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MACHINERY'S DATA SHEETS

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No. 17

Mechanics and Strength of Materials

PRICE 25 CENTS.

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Properties of Sections for Punch and Shear Frames.....37

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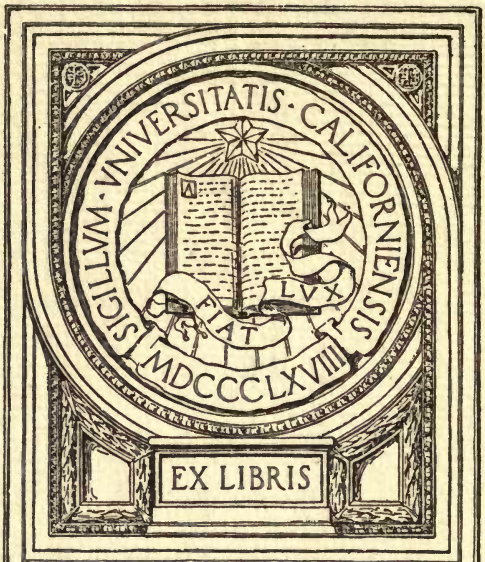
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MACHINERY'S DATA SHEET SERIES

COMPILED FROM MACHINERY'S MONTHLY DATA SHEETS AND ARRANGED WITH EXPLANATORY NOTES

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In the following pages are compiled a number of concise tables and diagrams relating to mechanics and the strength of materials, carefully selected from MACHINERY'S monthly Data Sheets, issued as supplements to the Engineering and Railway editions of MACHINERY since September, 1898. Several additional tables also are included.

In order to enhance the value of the tables, brief explanatory notes have been provided wherever necessary. In some of these notes references are made to articles which have appeared in MACHINERY, and to matter published in MACHINERY'S Reference Series, giving additional information on the subject. These references will be of considerable value to readers who wish to make a more thorough study of the subject. In a note at the foot of each table, reference is made to the page on which the explanatory note relating to the table appears.

MECHANICS

Rules and Formulas in Mechanics

On pages 4 to 11, inclusive, is given a collection of rules and formulas in mechanics, covering the subject in a comprehensive manner. The subjects treated are work, momentum, energy, centrifugal force, center of gravity, moment of inertia, radius of gyration, falling bodies, accelerated motion in a straight line, pendulum, inclined plane, friction, moments, safety valve, prony brake, strap brake, tackle-block, epicyclic gears, countershaft, crank and connecting-rod, toggle-joint, differential pulley, suspended cable, friction clutch, parallelogram of forces, triangle of forces, polygon of forces, and stresses in a crane. [MACHINERY'S Reference Series No. 5, First Principles of Theoretical Mechanics.]

Forces on Inclined Planes

On pages 12 and 13 a table is given to find the force required for moving a body along an inclined plane. The friction on the plane is not taken into account. The first column in the table gives the per cent of grade, or the rise in feet per 100 feet. The second column gives the angle in degrees and minutes corresponding to this rise. The third and fourth columns give the sine and cosine of the angle, and the fifth column the pull in pounds required for moving one ton along the inclined surface. The last column gives the perpendicular pressure on the plane per ton.

For example, assume that it is required to move a body weighing two tons along an inclined plane having a rise of 10 feet in 100 feet. What power would need to be exerted, the friction not being taken into consideration? To find the answer from the table, locate 10 in the left-hand column; following the line from 10 horizontally, we find that the power necessary for one ton is 199.2 pounds, and hence for two tons, 398.4 pounds. Of course, as the friction must be taken into consideration, the power required to pull the load will have to be increased according to the character of the sliding surfaces.

Calculating Centrifugal Force

Centrifugal force, as it is somewhat vaguely called, is not really a force residing in the revolving body and tending to urge it away from the center; it is rather the extraneous force which has to be exerted to restrain the body in its circular path, and prevent it from following the tangential direction which it constantly tries to take in accordance with Newton's law, *viz.*, that a moving body will continuously follow a straight line, unless acted upon by some outside force. This restraining force is directly proportional to the radius of the circle described by the center of gravity or center of mass of the revolving body, its weight (or more strictly, its mass), and the square of the number of revolutions per minute. It may be calculated by the formula:

$$F = 0.000341\, WRn^2$$

in which

F = centrifugal force, in pounds,
W = weight of the revolving body, in pounds,
R = radius of circular path described by the center of mass of the revolving body, in feet,
n = number of revolutions per minute.

The accompanying diagrams shown on pages 14 to 17, inclusive, were prepared to give directly, without calculations, the centrifugal force per one

(Continued on page 18.)

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WORK

Force is equivalent to a push or pull and is measured in pounds.

Work (in foot-pounds) = Force (in lbs.) x distance moved (in ft.); 33000 ft.-lbs. per minute or 550 ft.-lbs. per second = 1 Horsepower.

MOMENTUM

Momentum = mass x vel. in ft. per sec. $= Mv = Ft = \frac{wv}{32.16}$, where F = acting force and t = time in sec. that it acts. For recoil of a gun $WV = wv$, where W = wt. gun, w = wt. shot, V = vel. recoil, v = vel. shot.

ENERGY

Potential Energy: $E = wh$. *Kinetic*: $E = \frac{wv^2}{2g}$.

Force of hammer blow $= F = \frac{wv^2}{2gd} + w$, where d = distance in ft. moved by object struck; w + v refer to the hammer.

Hoisting a weight: Tension in rope $= Q = w\left(1 + \frac{a}{g}\right)$ where w = wt. in lbs. and a = acceleration in ft. p.s.

Energy rotating body: $E = \frac{2\pi^2 n^2 k^2 w}{g}$ where w = total wt., n = rev. per sec. and k = radius of gyration in feet.

Cylinder rolling down inclined plane: $v = \sqrt{\frac{4gh}{3}}$

CENTRIFUGAL FORCE

Centrifugal force $= \frac{Wv^2}{gR} = 0.00034\,WRN^2$

Total stress resisted by rim section $= 0.000054\,WRN^2$

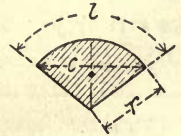
W = weight of rim in pounds; v = velocity of rim in ft. per second; g = 32.16; R = mean radius of rim in ft.; N = revolutions per minute.

$$N = \frac{180}{\pi}\sqrt{\frac{gS}{(r_1^2 + r_1 r_2 + r_2^2)w}}$$

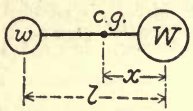
N = bursting speed of disk in rev. per min.; g = 32.16; S = ultimate strength of material in lbs. per sq. inch; r_1 and r_2 = radii in inches, as shown in figure; w = weight of material in lbs. per cubic inch.

CENTER OF GRAVITY.

Body suspended from c.g. has no tendency to rotate.
Center of gravity of regular figures is at geometrical center; of a triangle $\frac{2}{3}$ *distance from any angle to middle of opposite side; of semi-circle on middle radius . 4244 r from center; of sector* $\frac{2cr}{3l}$ *from center; of segment,* $\frac{c^3}{12a}$ *from center (where c = chord and a = area); of cone or pyramid,* $\frac{1}{4}$ *distance from center of base to apex.*

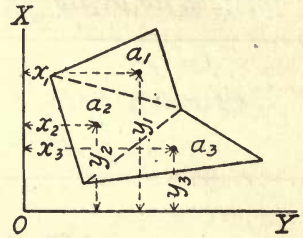


C. G. of 2 bodies, $x = \frac{wl}{w+W}$.



General Formulas $- x = \frac{a_1 x_1 + a_2 x_2 + a_3 x_3}{a_1 + a_2 + a_3}$

$$y = \frac{a_1 y_1 + a_2 y_2 + a_3 y_3}{a_1 + a_2 + a_3}$$



Volume of a solid generated by the revolution of a surface about an axis in the same plane with it = area of the surface × circum. described by its center of gravity.

MOMENT OF INERTIA.

Moment of Inertia of rotating body = products of weights of particles × squares of distances from the axis = $I = w_1 r_1^2 + w_2 r_2^2 + w_3 r_3^2$ *etc.* w_1, w_2, *etc. = wts. of particles;* r_1, r_2, *etc. = distances from axis in same units as the volumes of the particles of which weights are taken.*

RADIUS OF GYRATION.

Center of Gyration of rotating body is point at which weight may be assumed concentrated. Radius of Gyration = k = distance from center of rotation to center of gyration. For circular disc, $k = \frac{r}{\sqrt{2}}$

" " ring, $k = \sqrt{\frac{R^2 + r^2}{2}}$

MOTION.

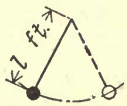
Falling Bodies: $h = \frac{v^2}{2g} = \frac{1}{2} g t^2$; $v = gt = \frac{2h}{t} = \sqrt{2gh}$; $t = \frac{v}{g} = \frac{2h}{v} = \sqrt{\frac{2h}{g}}$

Velocity at end of		Space passed through at end of		Space passed through during	
1st. Second	$= g$	1st Sec.	$= \frac{g}{2}$	1st Sec	$= \frac{g}{2}$
2d. "	$= 2g$	2d. "	$= 4\frac{g}{2}$	2d. "	$= 3\frac{g}{2}$
3d. "	$= 3g$	3d. "	$= 9\frac{g}{2}$	3d. "	$= 5\frac{g}{2}$
4th "	$= 4g$	4th. "	$= 16\frac{g}{2}$	4th. "	$= 7\frac{g}{2}$

Accelerated Motion in Straight Line: $F = Ma = \frac{w}{g} a$; $a = \frac{F}{w} g$; $s = \frac{v^2}{2a} = \frac{1}{2} a t^2$

$v = at = \frac{2s}{t} = \sqrt{2as}$. For retarded motion, $v = V - at$; $s = Vt - \frac{1}{2} at^2$.

Simple Pendulum: $= 39.102'$; t is traveled and varies



Time of 1 beat $= t = \pi \sqrt{\frac{l}{g}}$; seconds pendulum independent of w or length of arc as sq. root of l.

Conical Pendulum $N = \frac{30}{\pi} \sqrt{\frac{g}{h}}$; $h = \frac{2941}{N^2}$ only on the speed.

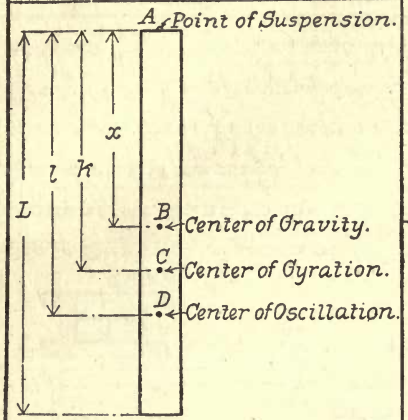
Time of revolution $= t = 2\pi \sqrt{\frac{h}{g}}$; h is independent of w or l and depends.

Inclined Plane: Velocity of sliding body $= v = \sqrt{2gh}$; v depends only on vertical height of descent: time of descent varies with incline and shape of plane. Cycloid gives fastest time.

Notation:

h = height in feet
v = vel. in ft. per sec.
g = 32.16
t = time in sec.
F = force in lbs.
w = wt. in lbs.
M = mass $= \frac{w}{g}$
a = acceleration in ft. per sec. per sec.
s = distance in ft.
V = initial vel.
π = 3.1416
N = no. rev. per min.

COMPOUND PENDULUM.



The Pendulum will beat in the same time whether hung from A or D.

It will also beat in the same time as a simple pendulum of length l.

Moment of Inertia $= I = \frac{wL^2}{3}$

$= wlx$; $l = \frac{I}{wx}$; $k = \sqrt{xl}$.

w = total weight.

The above formulas express the relations between the centers in above sketch.

Distances x and l can be found by experiment.

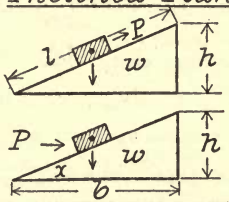
FRICTION.

Friction increases with pressure and is independent of velocity and extent of surfaces.

Fluid friction is independent of pressure and proportional to area of surface and square of velocity.

Coefficient of friction (f) = $\frac{\text{frictional resistance}}{\text{normal pressure.}}$

Inclined Planes.



	without Friction	with Friction
	$P = w\frac{h}{l}$	$P = w\frac{h+bf}{l}$
	$P = w\frac{h}{b}$	$P = w(\tan x + \tan y)$

y = angle of repose.

Work Done in Overcoming Friction — in inch-pounds.

Journal: $\pi f P d n$

Collar Bearing or square thread screw: $\frac{4}{3}\pi f n P \frac{r_1^3 - r_2^3}{r_1^2 - r_2^2}$

Flat Pivot: $\frac{4}{3}\pi f n P r$

f = coef. friction.

P = load in lbs.

r = radius in inches.

n = rev. per min.

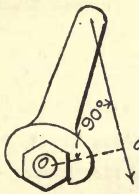
Ratio of Tensions of Band on Pulley at Point of Slipping.

Contact. f =	.2	.3	.4	.5
60°	1.23	1.37	1.52	1.69
120°	1.52	1.87	2.31	2.85
180°	1.87	2.56	3.51	4.81
240°	2.31	3.51	5.34	8.12

Coeffecients of Sliding Friction.

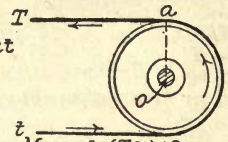
Wood on wood, dry	.25 to .5
" " greased	.02 " .1
Metal on metal, dry	.15 " .3
" " oiled intermittenily	.07 " .08
" " " continuously	.04 " .06
Leather on wood, dry	.3 " .5
" metal, dry	.56
" " greased	.23

LOW'S POCKET-BOOK.

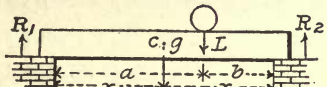


When pull is in direction of the arrow Moment = F × a.

Moments: The moment or turning effect of a force about a point is measured by the product of the force and the perpendicular distance from the point to the line of action of the force.



If the force is taken in lbs. and distance in ft., moment will be in foot-pounds, which must not be confounded with foot-pounds of work.

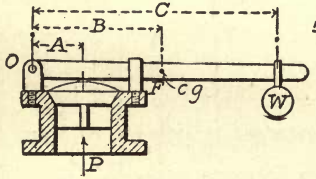


W = wt. beam, L = wt. load.

Let R_1 and R_2 be the re-action of the two supports of a beam. To find their values take moments about one support.

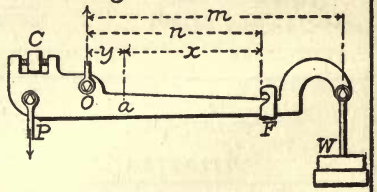
Thus, $R_1 \times C = W \times x + L \times b$ .or

$$R_1 = \frac{Wx + Lb}{C} \quad \text{and} \quad R_2 = L + W - R_1 .$$



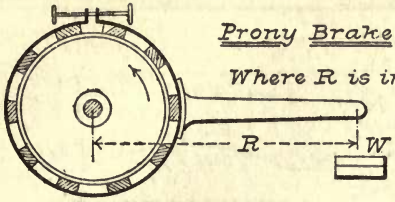
Safety Valve: P = total pressure on valve. W = wt of ball and F = wt. of lever. Taking moments about O, $P \times A$ tends to raise lever and is balanced by $F \times B + W \times C$.

$$P = \frac{F \times B + W \times C}{A} \; ; \; C = \frac{PA - FB}{W} ; \; W = \frac{PA - FB}{C}$$



Scale Beam: Fulcrum is at O. x = section of beam to be graduated. Counterpoise C balances the lever. F in position shown and W removed has same effect as with F placed at a and W on scale pan Hence, taking moments, $Fn = Wm + Fy$, whence, $Fx = Wm$ and $F = \frac{Wm}{x}$ Having found F, the zero point a must be located so that beam will balance with F at a and W removed.

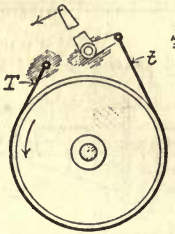
Principle of Work: The foot-pounds of work applied to a machine must equal the number of foot-pounds of work given up by the machine plus the number absorbed by friction.



Prony Brake: $H.P. = \frac{2\pi \times R \times N \times W}{33000}$

Where R is in feet, N = Rev. per Min. and W = weight in pan in pounds.

By making R = 63.02", $H.P. = \frac{N \times W}{1000}$

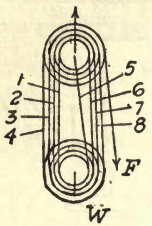


Strap Brake:

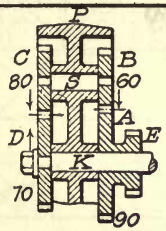
T = greatest stress in band; t = pull in pounds that lever must exert. P = turning force at surface of pulley that is to be overcome by action of brake.

Arc of Contact of Band.	Values of Greatest Stress in Band.	Values of Pull to be exerted by Lever.
115°	T = 5.52 P	t = .82 T
172°	T = 3.86 P	t = .73 T
229°	T = 3.03 P	t = .67 T
287°	T = 2.54 P	t = .6 T
344°	T = 2.22 P	t = .55 T

The above assumes a coeffecient of friction of .1 and is adapted from Reuleaux.

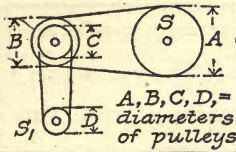


Tackle-Block: By the principle of work F × its distance moved = W × its distance. The distance moved by W depends upon number of ropes leaving lower pulley = N. In sketch N = 8; therefore W must move $\frac{1}{8}$ as far as F and would be 8 times as great. $W = FN$ and $F = \frac{W}{N}$.



Epicyclic Gears: Pulley P turns on shaft K and carries spindle S to which B and C are fastened. D turns with K and A is rotated upon K through Pinion E. The numbers of teeth of each pinion are indicated. Assume A to make +5 turns while P makes -10 turns, right-hand rotation being designated by + and left-hand by -. Required, number turns made by D.

First, assume all wheels to be locked together and to turn with P about K. Then A and D each make -10 turns. Second, assume P to be stationary and A to turn back to original position. Then D will make $10 \times \frac{90 \times 80}{60 \times 10} = 10 \times \frac{12}{7} = +17\frac{1}{7}$ turns (The sign + being determined by inspection). Third, with P still stationary, turn A the required +5 turns. Then D will make $\frac{12}{7} \times 5 = +8\frac{4}{7}$. Total movement of D, $-10 + 17\frac{1}{7} + 8\frac{4}{7} = +15\frac{5}{7}$ turns.

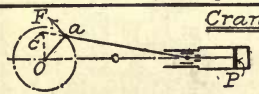


Counter-shaft S = speed of first pulley. S_1 = " " last "

Drivers.	Driven.
Then $S \times A \times C$ =	$S_1 \times B \times D$.

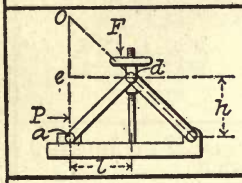
A, B, C, D, = diameters of pulleys.

$$A = \frac{S_1 \times B \times D}{S \times C} \; ; \; B = \frac{S \times A \times C}{S_1 \times D} \; ; \; C = \frac{S_1 \times B \times D}{S \times A} \; ; \; S_1 = \frac{S \times A \times C}{B \times D}$$



Crank and Connecting-Rod:

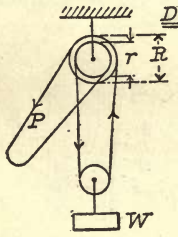
Tagential Force $F = \frac{P \times OC}{Oa}$, OC being a perpendicular dropped to center-line of motion at O, from center line of rod.



Toggle Joint

$P = \frac{F \times de}{aO}$ When the two arms are equal $P = \frac{F \times l}{2 \times h}$

A double toggle joint does not increase the pressure exerted so long as the relative distances moved by F and P remain the same.



Differential Pulley

$$P \times R = \frac{W}{2}(R - r)$$

$$P = \frac{W(R-r)}{2R}$$

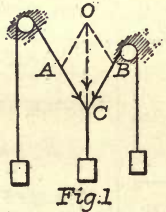


Fig. 1

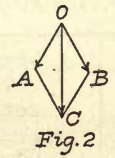


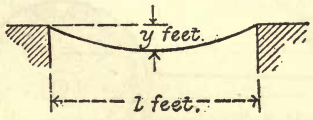
Fig. 2

Parallelogram of Forces.

The forces acting in Fig. are represented by the parallelogram in Fig. 2

OA and OB = magnitude and direction of two forces and OC = magnitude and direction of resultant.

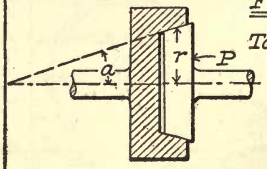
Suspended Cable.



T = greatest tension $= \frac{wl^2}{8y} + wy$

w = wt. of one foot.

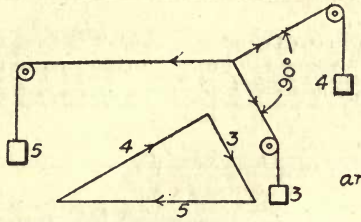
Friction Clutch.



Taper on each side 1 in 16.

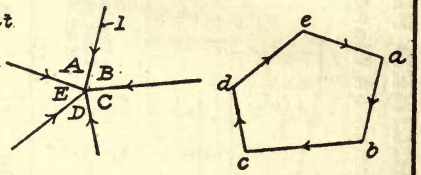
M = Moment of driving force.
f = Coef. friction.

$P = \frac{M}{rf}(\sin a + f \cos a)$

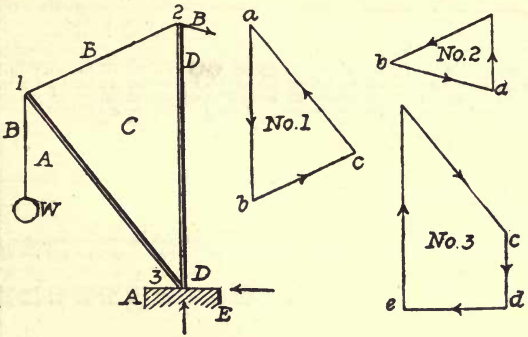


Triangle of Forces : If three forces balance when acting either toward or from a point, they may be represented by the sides of a triangle drawn parallel to the forces and taken the same way around. Can be tested by weights, cords and pulleys arranged as shown.

Polygon of Forces: Any number of forces in a plane and acting at a point will balance if they can be represented by the sides of a polygon parallel to the forces and taken the same way round.



Bow's Notation is used for designating the above forces. Thus, force No.1 is called "force AB" and is represented by line ab in the diagram.



Stresses in a Crane:

Forces acting about joint 1 are a pull in AB and a pull in BC which are resisted by an upward thrust in AC. These are represented by ab, bc and ca in No.1

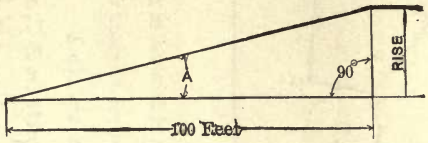
Forces acting about joint 2 are a pull in BC, and a pull in BD which are resisted by an upward thrust in CD. Stresses shown in No.2. bc is taken from No1, but the direction of the force is reversed.

In Joint 3 there are downward thrusts in AC and CD, and reactions AE and DE Diagram in No.3 where ac and cd are taken from No's.1 and 2.

All diagrams must be so drawn that the forces follow around in the same direction.

TABLE OF FORCES ON INCLINED PLANES.

Tensions and Pressures are in Pounds. Friction on Plane is not considered.



Per Cent. of Grade. Rise, Feet per 100 Feet.	Angle A.	Sine.	Cosine.	Tension in Cable per Ton of 2000 lbs.	Perpendicular Pressure on Plane per ton of 2000 lbs.
1	0° 35′	.0101	.9999	20.2	1999.8
2	1° 9′	.0200	.9997	40.0	1999.4
3	1° 44′	.0302	.9995	60.4	1999.0
4	2° 18′	.0401	.9991	80.2	1998.2
5	2° 52′	.0500	.9987	100.0	1997.4
6	3° 27′	.0601	.9981	120.2	1996.2
7	4° 1′	.0700	.9975	140.0	1995.0
8	4° 35′	.0799	.9968	159.8	1993.6
9	5° 9′	.0897	.9959	179.4	1991.8
10	5° 43′	.0996	.9950	199.2	1990.0
11	6° 17′	.1094	.9939	218.8	1987.8
12	6° 51′	.1192	.9928	238.4	1985.6
13	7° 25′	.1290	.9916	258.0	1983.2
14	7° 59′	.1388	.9903	277.6	1980.6
15	8° 32′	.1483	.9889	296.6	1977.8
16	9° 6′	.1581	.9874	316.2	1974.8
17	9° 39′	.1676	.9858	335.2	1971.6
18	10° 13′	.1773	.9841	354.6	1968.2
19	10° 46′	.1868	.9823	373.6	1964.6
20	11° 19′	.1962	.9805	392.4	1961.0
21	11° 52′	.2056	.9786	411.2	1957.2
22	12° 25′	.2150	.9766	430.0	1953.2
23	12° 58′	.2243	.9745	448.6	1949.0
24	13° 30′	.2334	.9723	466.8	1944.6
25	14° 3′	.2427	.9700	485.4	1940.0
26	14° 35′	.2517	.9677	503.4	1935.4
27	15° 7′	.2607	.9653	521.4	1930.6
28	15° 39′	.2697	.9629	539.4	1925.8
29	16° 11′	.2787	.9603	557.4	1920.6
30	16° 42′	.2873	.9578	574.6	1915.6
31	17° 14′	.2962	.9551	592.4	1910.2
32	17° 45′	.3048	.9523	609.6	1904.6
33	18° 16′	.3134	.9496	626.8	1899.2
34	18° 47′	.3219	.9467	643.8	1893.4

Contributed by Chas. Kuderer, MACHINERY'S Data Sheet No. 22. Explanatory note: Page 3.

TABLE OF FORCES ON INCLINED PLANES (Continued).

Per Cent. of Grade. Rise, Feet per 100 Feet.	Angle A.	Sine.	Cosine.	Tension in Cable per Ton of 2000 lbs.	Perpendicular Pressure on Plane per ton of 2000 lbs.
35	19° 18′	.3305	.9438	661.0	1887.6
36	19° 48′	.3387	.9408	677.4	1881.6
37	20° 19′	.3472	.9377	694.4	1875.4
38	20° 49′	.3553	.9347	710.6	1869.4
39	21° 19′	.3635	.9315	727.0	1863.0
40	21° 49′	.3716	.9283	743.2	1856.6
41	22° 18′	.3794	.9252	758.8	1850.4
42	22° 47′	.3872	.9219	774.4	1843.8
43	23° 17′	.3952	.9185	790.4	1837.0
44	23° 45′	.4027	.9153	805.4	1830.6
45	24° 14′	.4104	.9118	820.8	1823.6
46	24° 43′	.4181	.9083	836.2	1816.6
47	25° 11′	.4255	.9049	851.0	1809.8
48	25° 39′	.4328	.9014	865.6	1802.8
49	26° 7′	.4402	.8978	880.4	1795.6
50	26° 34′	.4472	.8944	894.4	1788.8
51	27° 2′	.4545	.8907	909.0	1781.4
52	27° 29′	.4614	.8871	922.8	1774.2
53	27° 56′	.4684	.8834	936.8	1766.8
54	28° 23′	.4753	.8797	950.6	1759.4
55	28° 49′	.4820	.8761	964.0	1752.2
56	29° 15′	.4886	.8724	977.2	1744.8
57	29° 41′	.4952	.8687	990.4	1737.4
58	30° 7′	.5017	.8650	1003.4	1730.0
59	30° 33′	.5082	.8611	1016.4	1722.2
60	30° 58′	.5145	.8574	1029.0	1714.8
61	31° 23′	.5207	.8537	1041.4	1707.4
62	31° 48′	.5268	.8498	1053.8	1699.6
63	32° 13′	.5331	.8460	1066.2	1692.0
64	32° 38′	.5392	.8421	1078.4	1684.2
65	33° 2′	.5451	.8383	1090.2	1676.6
66	33° 26′	.5509	.8345	1101.8	1669.0
67	33° 50′	.5567	.8306	1013.4	1661.2
68	34° 13′	.5623	.8269	1124.6	1653.8
69	34° 37′	.5680	.8229	1136.0	1645.8
70	35° 0′	.5735	.8191	1147.0	1638.2
71	35° 23′	.5790	.8152	1158.0	1630.4
72	35° 46′	.5844	.8114	1168.8	1622.8
73	36° 8′	.5896	.8076	1179.2	1615.2
74	36° 31′	.5950	.8036	1190.0	1607.2
75	36° 53′	.6002	.7998	1200.4	1599.6

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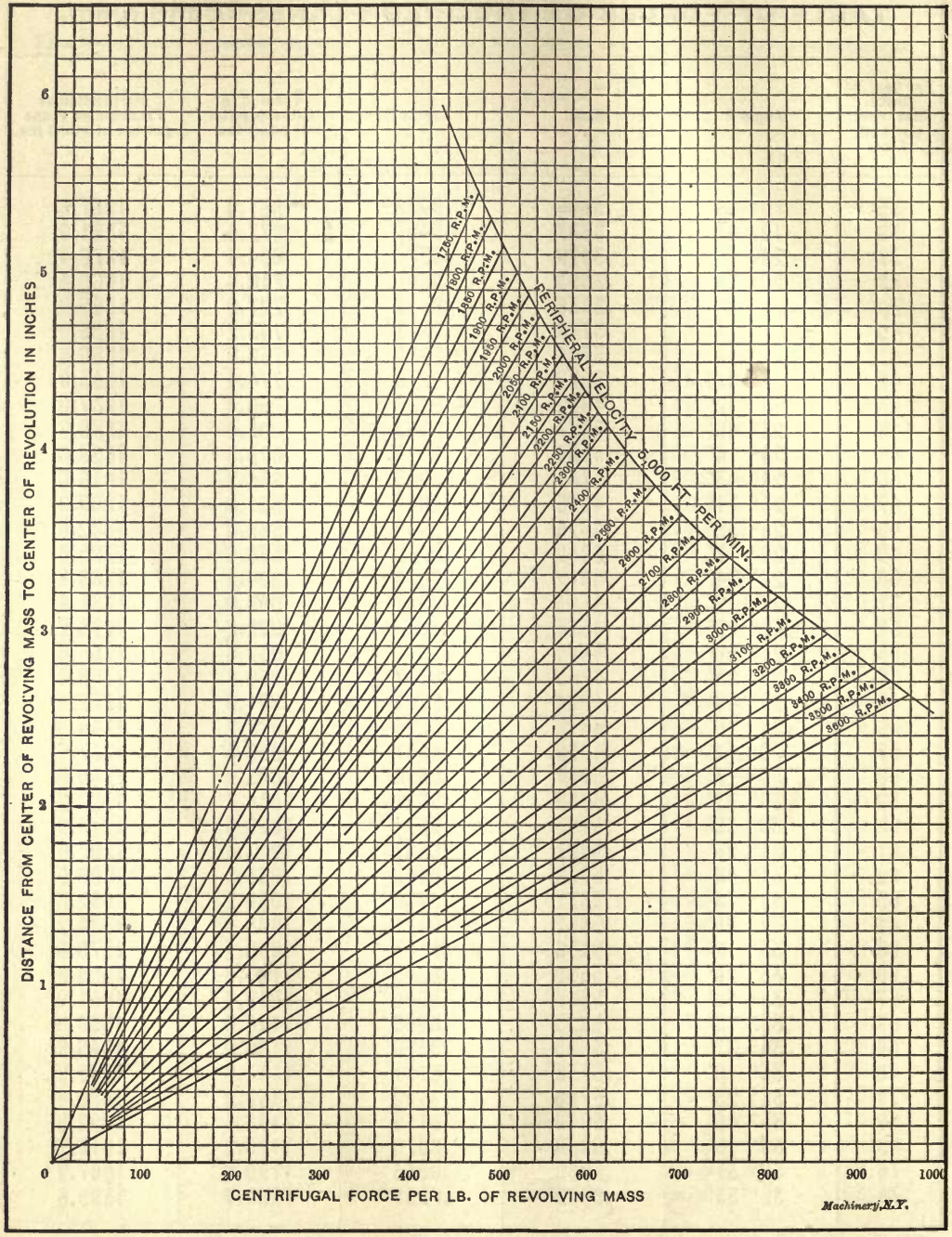
CENTRIFUGAL FORCE PER POUND OF REVOLVING MASS—I



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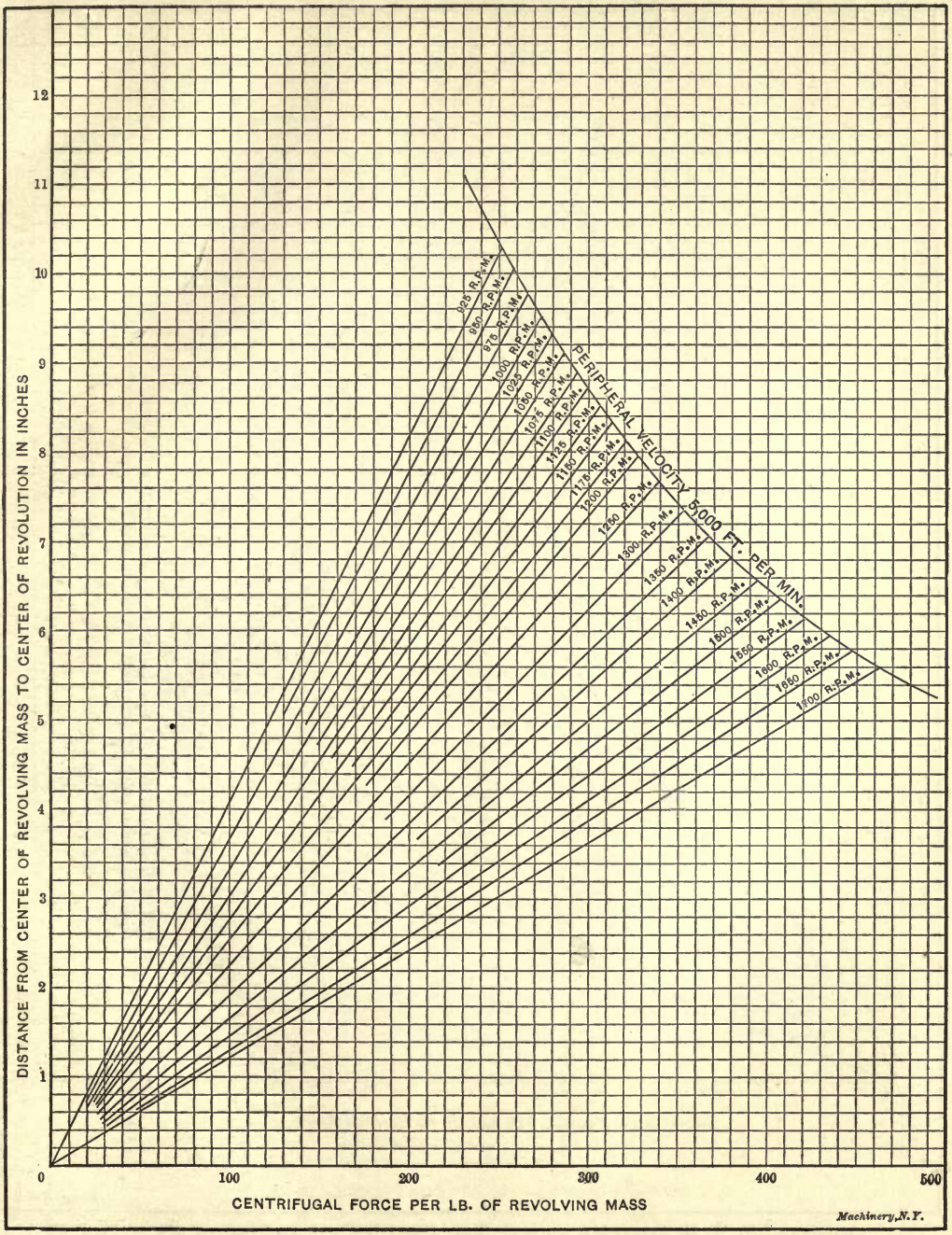
CENTRIFUGAL FORCE PER POUND OF REVOLVING MASS—II



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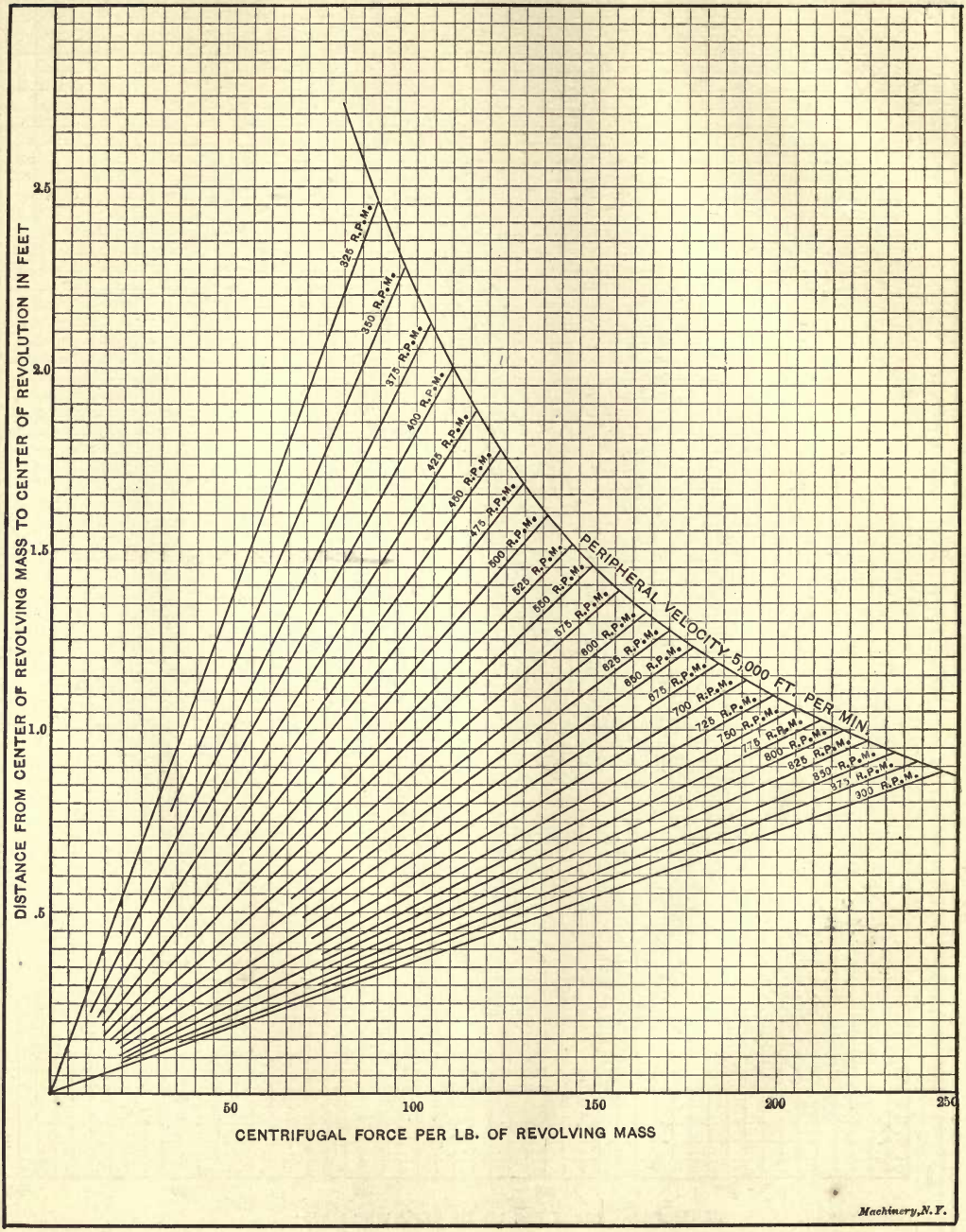
CENTRIFUGAL FORCE PER POUND OF REVOLVING MASS—III



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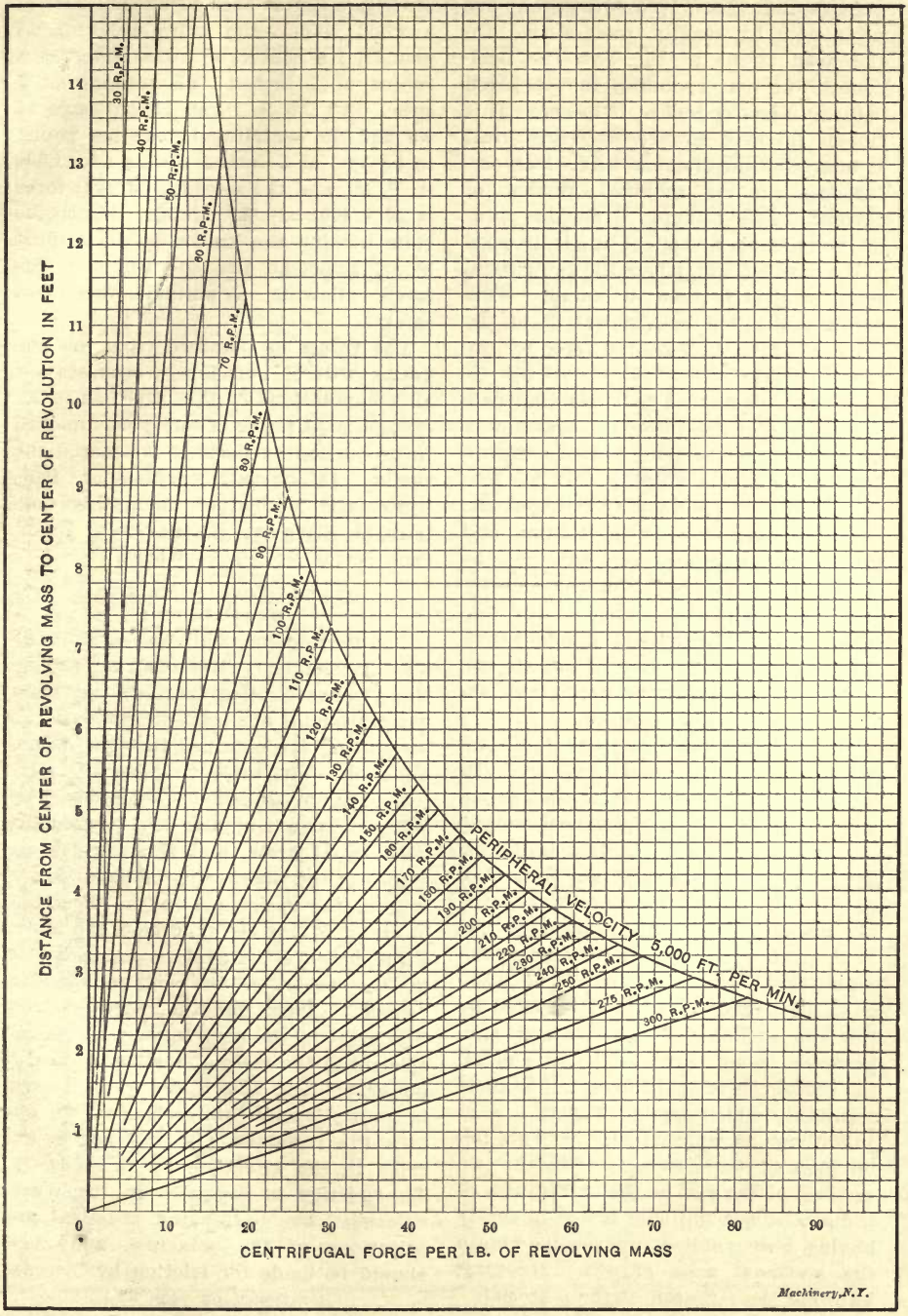
CENTRIFUGAL FORCE PER POUND OF REVOLVING MASS—IV



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pound for various radii and revolutions per minute. The way in which they are used will be readily understood. On the graduations at the left, the horizontal line corresponding to the given radius, in feet or inches, is located. This line is followed toward the right until it intersects the diagonal line which corresponds to the required number of revolutions per minute. From this point of intersection, a vertical line is dropped to the base margin, where the centrifugal force is directly read in pounds. This result multiplied by the weight of the body will give the required force for the case in hand.

It will be observed that the diagonals for the rate of revolution are terminated by a curve at the points where the intersections give a velocity of 5,000 feet per minute. This velocity is about the limit for cast-iron flywheel rims and similar parts, whose strength can be shown to be a function of the velocity and the physical properties of the material only. For speeds greater than this, each individual case should be calculated from data giving exact information on every point required.

As a simple case, suppose it is required to find the centrifugal force in the rim of a flywheel used on a gas engine. The rim of the flywheel weighs 500 pounds, the mean radius is 3 feet, and the speed is 250 R. P. M. Referring to page 17, we find the centrifugal force per pound at 3 feet radius and 250 R. P. M. to be 64. Hence the sum of the centrifugal forces in the rim is $64 \times 500 = 32{,}000$ pounds. The force resisted by the two sections of the flywheel rim, however, is not equal to the sum of all the radial centrifugal forces, but to their resultant, which equals $32{,}000 \div \pi = 10{,}200$ pounds, approximately. This latter force is the force resisted by the two sections of the rim at the extremities of a diameter. A suitable factor of safety having been applied, we readily obtain the sectional area of rim necessary, knowing the strength of the material.

Suppose it is required to find the centrifugal force exerted by the knife of a wood planer, the knife weighing 28 pounds, its center of mass being at a radius of 5 inches, and running at a speed of 1,800 R. P. M. From page 14 we find the centrifugal force per pound to be 460, at 5 inches radius and 1,800 R. P. M., and the total centrifugal force is $28 \times 460 = 12{,}880$ pounds. Hence the bolts holding the knives in place must be of sufficient size to overcome this force, allowing a suitable factor of safety.

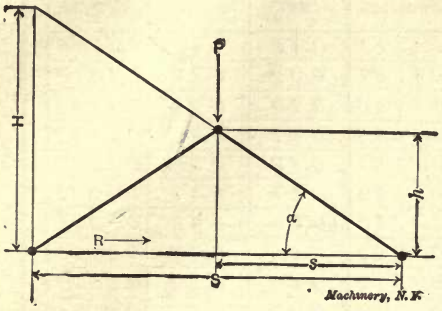
The values as obtained from the diagrams will be sufficiently accurate for all computations of this kind, as in all cases a large factor of safety is employed in proportioning parts to withstand the strain. [MACHINERY, September, 1905, Systematic Method of Computing Centrifugal Stresses; MACHINERY'S Reference Series No. 40, Flywheels.]

Power of Toggle-joints with Equal Arms

The toggle-joint, while one of the simplest mechanisms to construct, sometimes causes considerable confusion when attempts are made to calculate the forces that are obtained through its application. The table on page 19 is intended to obviate some of the difficulties. When the power applied to a toggle-joint with equal arms, and the angle a as shown in the illustration on page 19, are known, the resistance in the direction of arrow R may be found from the table. First measure the angle a and locate it in the table in the column headed "Angle." Then find the corresponding coefficient in the next column. This coefficient is the ratio of resistance to the power applied, and if the given power is multiplied by this coefficient, we obtain the resistance, or the power exerted in the direction of the arrow R. The friction is neglected in these calculations, but in making practical applications of the principle, allowance should be made for friction by increas-

(Continued on page 34.)

POWERS OF TOGGLE JOINTS WITH EQUAL ARMS.



P = power applied.
R = resistance.
a = given angle.
From formula $2R \sin a = P \cos a$.

$$\frac{R}{P} = \frac{\cos a}{2 \sin a} = \text{coefficient.}$$

or $R = P \times$ coefficient.

Equivalent expressions:

$$R = \frac{PS}{4h}; \quad R = \frac{Ps}{H}, \text{ as per diagram.}$$

To use the table, measure angle a, and find the coefficient in the table corresponding to the angle found. The coefficient is the ratio of the resistance to the power, and multiplying the power by the coefficient gives the resistance, neglecting friction.

Angle.	Coefficient.	Angle.	Coefficient.	Angle.	Coefficient.
0° 2′	862	1° 20′	21.5	5° 00′	5.71
0° 4′	456	1° 30′	19.1	5° 30′	5.19
0° 6′	285	1° 40′	17.2	6° 00′	4.76
0° 8′	216	1° 45′	16.4	6° 30′	4.39
0° 10′	171	1° 50′	15.6	7° 00′	4.07
0° 12′	143	2° 0′	14.3	7° 30′	3.79
0° 14′	122	2° 10′	13.2	8° 00′	3.58
0° 15′	115	2° 15′	12.7	8° 30′	3.35
0° 16′	107	2° 20′	12.5	9° 00′	3.15
0° 18′	95.4	2° 30′	11.5	9° 30′	2.99
0° 20′	85.8	2° 40′	10.7	10° 00′	2.84
0° 25′	68.6	2° 45′	10.4	11° 00′	2.57
0° 30′	57.3	2° 50′	10.1	12° 00′	2.35
0° 35′	49.1	3° 00′	9.54	13° 00′	2.17
0° 40′	42.8	3° 15′	8.81	14° 00′	2.00
0° 45′	38.2	3° 30′	8.17	15° 00′	1.87
0° 50′	34.4	3° 45′	7.63	16° 00′	1.74
0° 55′	31.2	4° 00′	7.25	17° 00′	1.64
1° 00′	28.6	4° 15′	6.73	18° 00′	1.54
1° 10′	24.6	4° 30′	6.35	19° 00′	1.45
1° 15′	22.9	4° 45′	6.02	20° 00′	1.37

HEIGHT, VELOCITY AND TIME OF FALLING BODIES—I

$H=\frac{v^2}{2g}$	$v=\sqrt{2gH}$	$t=\sqrt{\frac{2H}{g}}$	$H=\frac{v^2}{2g}$	$v=\sqrt{2gH}$	$t=\sqrt{\frac{2H}{g}}$	$H=\frac{v^2}{2g}$	$v=\sqrt{2gH}$	$t=\sqrt{\frac{2H}{g}}$
Head in Feet	Velocity in feet per Second	Time in Seconds	Head in Feet	Velocity in feet per Second	Time in Seconds	Head in Feet	Velocity in feet per Second	Time in Seconds
0.010	0.80	0.0248	0.20	3.59	0.1113	0.58	6.11	0.1894
0.015	0.98	0.0304	0.21	3.68	0.1141	0.59	6.17	0.1913
0.020	1.13	0.0350	0.22	3.76	0.1166	0.60	6.22	0.1928
0.025	1.27	0.0394	0.23	3.85	0.1193	0.61	6.28	0.1947
0.030	1.39	0.0431	0.24	3.93	0.1221	0.62	6.32	0.1959
0.035	1.50	0.0465	0.25	4.01	0.1243	0.63	6.37	0.1975
0.040	1.60	0.0496	0.26	4.09	0.1268	0.64	6.42	0.1990
0.045	1.70	0.0527	0.27	4.17	0.1293	0.65	6.47	0.1999
0.050	1.79	0.0555	0.28	4.25	0.1317	0.66	6.52	0.2021
0.055	1.88	0.0583	0.29	4.32	0.1339	0.67	6.57	0.2037
0.060	1.97	0.0611	0.30	4.39	0.1361	0.68	6.61	0.2049
0.065	2.04	0.0632	0.31	4.47	0.1386	0.69	6.66	0.2065
0.070	2.12	0.0657	0.32	4.54	0.1407	0.70	6.71	0.2080
0.075	2.20	0.0682	0.33	4.61	0.1429	0.71	6.76	0.2096
0.080	2.27	0.0704	0.34	4.68	0.1451	0.72	6.81	0.2111
0.085	2.34	0.0725	0.35	4.75	0.1472	0.73	6.86	0.2127
0.090	2.41	0.0747	0.36	4.81	0.1491	0.74	6.91	0.2142
0.095	2.47	0.0766	0.37	4.87	0.1510	0.75	6.95	0.2154
0.100	2.54	0.0787	0.38	4.94	0.1531	0.76	6.99	0.2167
0.105	2.60	0.0806	0.39	5.01	0.1553	0.77	7.04	0.2182
0.110	2.66	0.0825	0.40	5.07	0.1572	0.78	7.09	0.2198
0.115	2.72	0.0843	0.41	5.14	0.1593	0.79	7.13	0.2210
0.120	2.78	0.0862	0.42	5.20	0.1612	0.80	7.18	0.2226
0.125	2.84	0.0880	0.43	5.26	0.1634	0.81	7.22	0.2238
0.130	2.89	0.0896	0.44	5.32	0.1649	0.82	7.26	0.2251
0.135	2.95	0.0914	0.45	5.38	0.1668	0.83	7.31	0.2266
0.140	3.00	0.0930	0.46	5.44	0.1686	0.84	7.35	0.2278
0.145	3.05	0.0949	0.47	5.50	0.1705	0.85	7.40	0.2294
0.150	3.11	0.0964	0.48	5.56	0.1724	0.86	7.44	0.2306
0.155	3.16	0.0980	0.49	5.62	0.1742	0.87	7.48	0.2319
0.160	3.21	0.0995	0.50	5.67	0.1758	0.88	7.53	0.2334
0.165	3.26	0.1011	0.51	5.73	0.1779	0.89	7.57	0.2347
0.170	3.31	0.1026	0.52	5.79	0.1795	0.90	7.61	0.2359
0.175	3.36	0.1042	0.53	5.85	0.1813	0.91	7.65	0.2377
0.180	3.40	0.1054	0.54	5.90	0.1829	0.92	7.70	0.2387
0.185	3.45	0.1069	0.55	5.95	0.1844	0.93	7.74	0.2399
0.190	3.50	0.1085	0.56	6.00	0.1860	0.94	7.78	0.2412
0.195	3.55	0.1100	0.57	6.06	0.1879	0.95	7.82	0.2424

Contributed by Wm. N. Allman. Explanatory note: Page 34.

HEIGHT, VELOCITY AND TIME OF FALLING BODIES—II

$H=\frac{v^2}{2g}$ Head in Feet	$v=\sqrt{2gH}$ Velocity in feet per Second	$t=\sqrt{\frac{2H}{g}}$ Time in Seconds	$H=\frac{v^2}{2g}$ Head in Feet	$v=\sqrt{2gH}$ Velocity in feet per Second	$t=\sqrt{\frac{2H}{g}}$ Time in Seconds	$H=\frac{v^2}{2g}$ Head in Feet	$v=\sqrt{2gH}$ Velocity in feet per Second	$t=\sqrt{\frac{2H}{g}}$ Time in Seconds
0.96	7.86	0.2437	1.95	11.2	0.3482	7.4	21.8	0.6789
0.97	7.90	0.2449	2.00	11.4	0.3509	7.6	22.1	0.6878
0.98	7.94	0.2461	2.1	11.7	0.3590	7.8	22.4	0.6964
0.99	7.98	0.2474	2.2	11.9	0.3697	8.0	22.7	0.7048
1.00	8.03	0.2491	2.3	12.2	0.3770	8.2	23.0	0.7130
1.02	8.10	0.2518	2.4	12.4	0.3871	8.4	23.3	0.7210
1.04	8.18	0.2543	2.5	12.6	0.3968	8.6	23.5	0.7319
1.06	8.26	0.2567	2.6	12.9	0.4031	8.8	23.8	0.7395
1.08	8.34	0.2589	2.7	13.2	0.4091	9.0	24.1	0.7469
1.10	8.41	0.2616	2.8	13.4	0.4179	9.2	24.3	0.7572
1.12	8.49	0.2638	2.9	13.7	0.4234	9.4	24.6	0.7642
1.14	8.57	0.2660	3.0	13.9	0.4317	9.6	24.8	0.7742
1.16	8.64	0.2685	3.1	14.1	0.4397	9.8	25.1	0.7809
1.18	8.72	0.2706	3.2	14.3	0.4476	10.0	25.4	0.7866
1.20	8.79	0.2730	3.3	14.5	0.4552	10.5	26.0	0.8077
1.22	8.87	0.2751	3.4	14.8	0.4595	11.0	26.6	0.8277
1.24	8.94	0.2774	3.5	15.0	0.4667	11.5	27.2	0.8456
1.26	9.01	0.2797	3.6	15.2	0.4737	12.0	27.8	0.8633
1.28	9.08	0.2819	3.7	15.4	0.4805	12.5	28.4	0.8803
1.30	9.15	0.2842	3.8	15.6	0.4872	13.0	28.9	0.8997
1.32	9.21	0.2866	3.9	15.8	0.4937	13.5	29.5	0.9153
1.34	9.29	0.2885	4.0	16.0	0.5000	14.0	30.0	0.9333
1.36	9.36	0.2906	4.2	16.4	0.5122	14.5	30.5	0.9508
1.38	9.43	0.2927	4.4	16.8	0.5238	15.0	31.1	0.9646
1.40	9.49	0.2950	4.6	17.2	0.5343	15.5	31.6	0.9810
1.42	9.57	0.2968	4.8	17.6	0.5454	16.0	32.1	0.9969
1.44	9.63	0.2991	5.0	17.9	0.5587	16.5	32.6	1.0123
1.46	9.70	0.3010	5.2	18.3	0.5683	17.0	33.1	1.0272
1.48	9.77	0.3030	5.4	18.7	0.5775	17.5	33.6	1.0417
1.50	9.83	0.3052	5.6	19.0	0.5895	18.0	34.0	1.0588
1.55	9.98	0.3106	5.8	19.3	0.6010	18.5	34.5	1.0725
1.60	10.02	0.3137	6.0	19.7	0.6091	19.0	35.0	1.0857
1.65	10.30	0.3204	6.2	20.0	0.6200	19.5	35.4	1.1017
1.70	10.50	0.3238	6.4	20.3	0.6305	20.0	35.9	1.1142
1.75	10.60	0.3302	6.6	20.6	0.6408	20.5	36.3	1.1295
1.80	10.80	0.3333	6.8	20.9	0.6507	21.0	36.8	1.1413
1.85	10.90	0.3394	7.0	21.2	0.6604	21.5	37.2	1.1559
1.90	11.10	0.3423	7.2	21.5	0.6698	22.0	37.6	1.1702

Contributed by Wm. N. Allman. Explanatory note: Page 34.

HEIGHT, VELOCITY AND TIME OF FALLING BODIES—III

$H=\frac{v^2}{2g}$ Head in Feet	$v=\sqrt{2gH}$ Velocity in feet per Second	$t=\sqrt{\frac{2H}{g}}$ Time in Seconds	$H=\frac{v^2}{2g}$ Head in Feet	$v=\sqrt{2gH}$ Velocity in feet per Second	$t=\sqrt{\frac{2H}{g}}$ Time in Seconds	$H=\frac{v^2}{2g}$ Head in Feet	$v=\sqrt{2gH}$ Velocity in feet per Second	$t=\sqrt{\frac{2H}{g}}$ Time in Seconds
22.5	38.1	1.1811	53	58.4	1.8151	86	74.4	2.3118
23.0	38.5	1.1948	54	59.0	1.8305	87	74.8	2.3262
23.5	38.9	1.2082	55	59.5	1.8487	88	75.3	2.3373
24.0	39.3	1.2214	56	60.0	1.8667	89	75.7	2.3514
24.5	39.7	1.2343	57	60.6	1.8812	90	76.1	2.3653
25	40.1	1.2469	58	61.1	1.8985	91	76.5	2.3791
26	40.9	1.2714	59	61.6	1.9156	92	76.9	2.3927
27	41.7	1.2950	60	62.1	1.9324	93	77.4	2.4031
28	42.5	1.3176	61	62.7	1.9458	94	77.8	2.4165
29	43.2	1.3426	62	63.2	1.9620	95	78.2	2.4297
30	43.9	1.3667	63	63.7	1.9780	96	78.6	2.4427
31	44.7	1.3870	64	64.2	1.9938	97	79.0	2.4557
32	45.4	1.4097	65	64.7	2.0093	98	79.4	2.4685
33	46.1	1.4317	66	65.2	2.0245	99	79.8	2.4812
34	46.7	1.4561	67	65.7	2.0396	100	80.3	2.4907
35	47.4	1.4768	68	66.2	2.0544	125	89.7	2.7871
36	48.1	1.4968	69	66.7	2.0690	150	98.3	3.0519
37	48.8	1.5164	70	67.1	2.0864	175	106	3.3019
38	49.5	1.5354	71	67.6	2.1006	200	114	3.5088
39	50.1	1.5569	72	68.1	2.1145	225	120	3.7500
40	50.7	1.5779	73	68.5	2.1313	250	126	3.9683
41	51.3	1.5984	74	69.0	2.1449	275	133	4.1353
42	52.0	1.6154	75	69.5	2.1583	300	139	4.3165
43	52.6	1.6350	76	69.9	2.1745	350	150	4.6667
44	53.2	1.6541	77	70.4	2.1874	400	160	5.0000
45	53 8	1.6729	78	70.9	2.2003	450	170	5.2941
46	54.4	1.6912	79	71.3	2.2160	500	179	5.5866
47	55.0	1.7090	80	71.8	2.2284	550	188	5.8511
48	55.6	1.7266	81	72.2	2.2438	600	197	6.0914
49	56.2	1.7438	82	72.6	2.2590	700	212	6.6038
50	56.7	1.7637	83	73.1	2.2709	800	227	7.0485
51	57.3	1.7801	84	73.5	2.2857	900	241	7.4689
52	57.8	1.7993	85	74.0	2.2973	1000	254	7.8740

Contributed by Wm. N. Allman. Explanatory note: Page 34.

Kind of Metal	Weight per Cubic Inch	Weight per Cubic Foot	Ultimate Strength			Elastic Limit, Tension	Modulus of Rupture, Transverse	Modulus of Elasticity, Tension
			Tension	Compression	Shear			
Wrought Iron, small bars	0.280	485	55,000	38,000	45,000	28,000	40,000	26,000,000
Wrought Iron, plates			50,000		40,000	25,000		25,000,000
Wrought Iron, large forgings			45,000		35,000	22,500	30,000	25,000,000
Steel, O. H. plate			60,000	100,000	50,000	32,000		28,000,000
Steel, Bessemer	0.283	489	90,000					
Steel, machinery			90,000		80,000	50,000		29,000,000
Steel, crucible or tool	0.282	487	120,000			60,000		40,000,000
Cast Iron	0.260	450	18,000	75,000	25,000	Uncertain	36,000	18,000,000
Malleable Castings	0.256	442	36,000		42,000	16,000		
Steel Castings			45,000	100,000		18,000		30,000,000
Brass Castings	0.289	500	24,000	12,000				9,000,000
Copper Castings	0.321	555	24,000	75,000	24,000		30,000	15,000,000
Bronze, gun metal	0.309	534	36,000	100,000				10,000,000
Bronze, 10 Al. 90 Cu			85,000	132,000				
Bronze, phosphor			58,000		43,000	20,000		14,000,000
Aluminum Castings	0.092	159	28,000	13,000		14,000		11,000,000

ELEMENTARY FORMULAS

S = stress in pounds per square inch; W = load in pounds; A = area of cross-section in square inches; M = bending moment; I = moment of inertia; y = distance from center of gravity to most remote fiber; T = twisting moment; J = polar moment of inertia.

Simple tension, compression, or shear, $S = \frac{W}{A}$

Bending under transverse load, $M = \frac{S I}{y}$

Torsion or twisting, $T = \frac{S J}{y}$

For shafting we have:

$$d = \sqrt[3]{\frac{5.1\,T}{S}}; \text{ and } T = \frac{63{,}025 \text{ H.P.}}{N}$$

in which d = diameter of shaft; H.P. = horse-power transmitted; N = revolutions per minute.

COLUMNS SUBJECT TO BENDING

Rankine-Gordon formula: $P = \frac{fA}{1 + q\frac{l^2}{r^2}}$

P = ultimate resistance of column in pounds; f = crushing strength of material in pounds per square inch; A = area of cross-section in square inches; l = length of column in inches; r^2 = moment of inertia ÷ area of section.

VALUES OF q IN FORMULA

Material	Both Ends Fixed	Fixed and Round	Both Ends Round	Fixed and Free
Cast Iron	$\frac{1}{5000}$	$\frac{1.78}{5000}$	$\frac{4}{5000}$	$\frac{16}{5000}$
Wrought Iron	$\frac{1}{36000}$	$\frac{1.78}{36000}$	$\frac{4}{36000}$	$\frac{16}{36000}$
Steel	$\frac{1}{25000}$	$\frac{1.78}{25000}$	$\frac{4}{25000}$	$\frac{16}{25000}$

Square Flat Plates, Supported at all Four Edges. Load Uniformly Distributed Over Unsupported Surface of Plate.

Author and Reference	Formulas as given by Author	Total Load $W = PL^2$	Unit Fiber Stress in Pounds per Square Inch $f =$	$t^2 =$	Thickness Plate in Inches $t =$	$L^2 =$	Clear Span Between Supported Edges $L =$	Uniform Load per Unit of Surface $P =$
Grashof, Trautwines C.E. Pocket Book 1906, Page 493–494	$f = \frac{CL^2P}{4t^2}$ $P = \frac{4ft^2}{CL^2}$ $C = 1.125$	$3.56ft^2$	$0.28\frac{W}{t^2}$	$0.28\frac{W}{f}$	$0.53\sqrt{\frac{W}{f}}$			
			$0.28\frac{PL^2}{t^2}$	$0.28\frac{PL^2}{f}$	$0.53L\sqrt{\frac{P}{f}}$	$3.56\frac{ft^2}{P}$	$1.89t\sqrt{\frac{f}{P}}$	$3.56\frac{ft^2}{L^2}$
J. B. Johnson, The Materials of Construction 1897, Page 93	$t = 0.61L\sqrt{\frac{P}{f}}$	$2.67ft^2$	$0.375\frac{W}{t^2}$	$0.375\frac{W}{f}$	$0.61\sqrt{\frac{W}{f}}$			
			$0.375\frac{PL^2}{t^2}$	$0.375\frac{PL^2}{f}$	$0.61L\sqrt{\frac{P}{f}}$	$2.67\frac{ft^2}{P}$	$1.634t\sqrt{\frac{f}{P}}$	$2.67\frac{ft^2}{L^2}$
Rankine, Civil Engineering, Page 543	Bending Moment $M = \frac{WL}{16}$	$2.67ft^2$	$0.375\frac{W}{t^2}$	$0.375\frac{W}{f}$	$0.61\sqrt{\frac{W}{f}}$			
			$0.375\frac{PL^2}{t^2}$	$0.375\frac{PL^2}{f}$	$0.61L\sqrt{\frac{P}{f}}$	$2.67\frac{ft^2}{P}$	$1.634t\sqrt{\frac{f}{P}}$	$2.67\frac{ft^2}{L^2}$
Wm. F. Fischer	$\frac{WL}{24} = \frac{fLt^2}{6}$ or $M = M_1$	$4ft^2$	$0.25\frac{W}{t^2}$	$0.25\frac{W}{f}$	$0.5\sqrt{\frac{W}{f}}$			
			$0.25\frac{PL^2}{t^2}$	$0.25\frac{PL^2}{f}$	$0.5L\sqrt{\frac{P}{f}}$	$4\frac{ft^2}{P}$	$2t\sqrt{\frac{f}{P}}$	$4\frac{ft^2}{L^2}$

Contributed by William F. Fischer, MACHINERY'S Data Sheet No. 112. Explanatory note: Page 34.

FORMULAS FOR STRENGTH OF FLAT PLATES—II

Square Flat Plates Firmly Secured Along All Four Edges, Load Uniformly Distributed Over Unsupported Surface of Plate.

Author and Reference	Formulas as Given by Author	Total Load $PL^2 = W =$	Unit Fiber Stress Pounds per sq. in. $f =$	$t^2 =$	Thickness of Plate Inches $t =$	$L^2 =$	Clear Span Between Supported Edges $L =$	Uniform Load per Unit of Surface $P =$
Grashof, Trautwines C.E. Pocket Book 1906, Page 494	$f = \frac{CL^2P}{4t^2}$ $P = \frac{4ft^2}{CL^2}$ $C = 0.75$	$5.33ft^2$	$0.1875\frac{W}{t^2}$	$0.1875\frac{W}{f}$	$0.433\sqrt{\frac{W}{f}}$			
			$0.1875\frac{PL^2}{t^2}$	$0.1875\frac{PL^2}{f}$	$0.433L\sqrt{\frac{P}{f}}$	$5.33\frac{ft^2}{P}$	$2.31t\sqrt{\frac{f}{P}}$	$5.33\frac{ft^2}{L^2}$
J.B. Johnson, The Materials of Construction 1897 Page 73	$f = \frac{9PL^2}{32t^2}$ $t = 0.53L\sqrt{\frac{P}{f}}$	$3.6ft^2$	$0.28\frac{W}{t^2}$	$0.28\frac{W}{f}$	$0.53\sqrt{\frac{W}{f}}$			
			$0.28\frac{PL^2}{t^2}$	$0.28\frac{PL^2}{f}$	$0.53L\sqrt{\frac{P}{f}}$	$3.6\frac{ft^2}{P}$	$1.89t\sqrt{\frac{f}{P}}$	$3.6\frac{ft^2}{L^2}$
Unwin, Elements of Machine Design Page 73	$f = \frac{L^2P}{4t^2}$	$4ft^2$	$0.25\frac{W}{t^2}$	$0.25\frac{W}{f}$	$0.5\sqrt{\frac{W}{f}}$			
			$0.25\frac{PL^2}{t^2}$	$0.25\frac{PL^2}{f}$	$0.5L\sqrt{\frac{P}{f}}$	$4\frac{ft^2}{P}$	$2t\sqrt{\frac{f}{P}}$	$4\frac{ft^2}{L^2}$

Square Flat Plate, Supported At All Four Edges, Loaded at Center With a Concentrated Load W.

Author and Reference	Formulas as Given by Author	Central Load $W =$	Unit Stress in Extreme Fiber. Pounds per sq. Inch $f =$	$t^2 =$	Thickness Plate in Inches $t =$
Rankine, Civil Engineering, Page 543	Bending Moment $M = \frac{3WL}{16}$	$0.9ft^2$	$1.125\frac{W}{t^2}$	$1.125\frac{W}{f}$	$1.06\sqrt{\frac{W}{f}}$
Grashof, Trautwines C.E. Pocket Book, Page 493	$f = \frac{3CW}{4t^2}$ $W = \frac{4ft^2}{3C}$ $C = 2$	$0.667ft^2$	$1.5\frac{W}{t^2}$	$1.5\frac{W}{f}$	$1.23\sqrt{\frac{W}{f}}$

Square Flat Plate, Firmly Secured at all Four Edges, Loaded at Center with a Concentrated Load W.

Grashof, Trautwines C.E. Pocket Book, Page 493	$f = \frac{3CW}{4t^2}$ $W = \frac{4ft^2}{3C}$ $C = 1.75$	$0.762ft^2$	$1.31\frac{W}{t^2}$	$1.31\frac{W}{f}$	$1.144\sqrt{\frac{W}{f}}$

Flat Rectangular Plates, Supported at all Four Edges and Loaded with a Uniformly Distributed Load $W = PLl$.

Author and Reference	Formulas as Given by Author	Total Load W on Plate $=$	Pressure on Plate per Unit of Area $P=$	Unit Stress in Extreme Fiber of Material $f=$	Thickness of Plate, Inches $t=$
Johnson, Materials of Construction, $L = 2l$ or greater	$f = \frac{3Pl^2}{4t^2}$	$1.34\frac{fLt^2}{l}$		$0.75\frac{Wl}{Lt^2}$	$0.866\sqrt{\frac{Wl}{fL}}$
	$t = \frac{l}{2}\sqrt{\frac{3P}{f}}$		$1.34\frac{ft^2}{l^2}$	$0.75\frac{Pl^2}{t^2}$	$0.866l\sqrt{\frac{P}{f}}$
Johnson, Where $L = 1\frac{1}{2}l$ about	$f = \frac{3}{4}\cdot\frac{3Pl^2}{4t^2}$	$1.8\frac{fLt^2}{l}$		$0.56\frac{Wl}{Lt^2}$	$0.75\sqrt{\frac{Wl}{fL}}$
	$t = \frac{3}{4}l\sqrt{\frac{P}{f}}$		$1.78\frac{ft^2}{l^2}$	$0.56\frac{Pl^2}{t^2}$	$0.75l\sqrt{\frac{P}{f}}$
Rankine, Civil Engineering Page 543	$M = \frac{WL^4l}{8(L^4+l^4)}$	$1.34\frac{ft^2(L^4+l^4)}{L^3l}$		$0.75\frac{WL^3l}{t^2(L^4+l^4)}$	$0.866\sqrt{\frac{WL^3l}{f(L^4+l^4)}}$
			$1.34\frac{ft^2(L^4+l^4)}{L^4l^2}$	$0.75\frac{Pl^2L^4}{t^2(L^4+l^4)}$	$0.866l^2l\sqrt{\frac{P}{f(L^4+l^4)}}$
Grashof, Trautwines Pocket Book Page 493	$f = \frac{CPL^2l^2}{2t^2(L^2+l^2)}$ $C = 1.125$	$1.77\frac{ft^2(L^2+l^2)}{Ll}$		$0.56\frac{WLl}{t^2(L^2+l^2)}$	$0.75\sqrt{\frac{WLl}{f(L^2+l^2)}}$
			$1.77\frac{ft^2(L^2+l^2)}{L^2l^2}$	$0.56\frac{Pl^2l^2}{t^2(L^2+l^2)}$	$0.75Ll\sqrt{\frac{P}{f(L^2+l^2)}}$
Fischer	$\frac{Pl^2(2N+L)}{24} = \frac{fLt^2}{6}$				
			$\frac{4fLt^2}{l^2(2N+L)}$	$\frac{Pl^2(2N+L)}{4Lt^2}$	$0.5l\sqrt{\frac{P(2N+L)}{fL}}$

M = Maximum Bending Moment, Inch Pounds
L = Longest Span, and l = Shortest Span Between Edge of Supports
$N = L - l$ W, P, f, and t as given above.

Note:- If L and l are given in feet P = Pounds per sq. foot. If L and l are in inches, P = Pounds per sq. inch. $W = PlL$.

Flat Rectangular Plates, Firmly Secured at all Four Edges Loaded with a Uniformly Distributed Load $W = PLl$.

Author and Reference	Formulas as Given by Author	Total Load W on Plate =	Pressure on Plate per Unit of Area P =	Unit Stress in Extreme Fiber of Material f =	Thickness of Plate in Inches t =
Grashof, Trautwines C.E. Pocket Book, Page 493	$f = \frac{CPL^2l^2}{2t^2(L^2+l^2)}$ $C = 0.75$	$2.67\,\frac{ft^2(L^2+l^2)}{Ll}$		$0.375\,\frac{WLl}{t^2(L^2+l^2)}$	$0.62\sqrt{\frac{WLl}{f(L^2+l^2)}}$
			$2.67\,\frac{ft^2(L^2+l^2)}{L^2l^2}$	$0.375\,\frac{PL^2l^2}{t^2(L^2+l^2)}$	$0.62Ll\sqrt{\frac{P}{f(L^2+l^2)}}$
Unwin, Elements of Machine Design, Page 93	$f = \frac{PL^4l^2}{2t^2(L^4+l^4)}$	$2.\,\frac{ft^2(L^4+l^4)}{L^3l}$		$0.5\,\frac{WL^3l}{t^2(L^4+l^4)}$	$0.7\sqrt{\frac{WL^3l}{f(L^4+l^4)}}$
			$2.\,\frac{ft^2(L^4+l^4)}{L^4l^2}$	$0.5\,\frac{PL^4l^2}{t^2(L^4+l^4)}$	$0.7L^2l\sqrt{\frac{P}{f(L^4+l^4)}}$
Neglecting End Bearings Entirely Where $L = 2l$ or Greater, and Treating as a Simple Beam, Uniformly Loaded – See Below.					
Bending Moment $M = \frac{Wl}{12}$ or $M = \frac{PLl^2}{12}$	Resisting Moment $M_1 = \frac{fLt^2}{6}$ $\frac{Wl}{12} = \frac{fLt^2}{6}$	$2.\,\frac{fLt^2}{l}$		$0.5\,\frac{Wl}{Lt^2}$	$0.7\sqrt{\frac{Wl}{fl}}$
			$2.\,\frac{ft^2}{l^2}$	$0.5\,\frac{Pl^2}{t^2}$	$0.7l\sqrt{\frac{P}{f}}$
Assuming $\frac{3}{4}$ of Load to be Carried at the Sides and $\frac{1}{4}$ Carried at the Ends, Where $L = 1\frac{1}{2}\,l$ about, (Treated as a Simple Beam) – See Below.					
$M = \frac{3}{4}\cdot\frac{Wl}{12}$ or $M = \frac{3}{4}\cdot\frac{PLl^2}{12}$	$M_1 = \frac{fLt^2}{6}$ $\frac{3Wl}{48} = \frac{fLt^2}{6}$	$2.67\,\frac{fLt^2}{l}$		$0.375\,\frac{Wl}{Lt^2}$	$0.62\sqrt{\frac{Wl}{fL}}$
			$2.67\,\frac{ft^2}{l^2}$	$0.375\,\frac{Pl^2}{t^2}$	$0.62l\sqrt{\frac{P}{f}}$

M = Maximum Bending Moment, Inch Pounds
L = Longest Span, Between Supports
l = Shortest Span, Between Supports

W, P, f, and t as given above
Note:- If L and l are given in inches, P = pounds per sq. inch.
If L and l are given in feet, P = pounds per sq. foot.

Rectangular Flat Plates, Supported at all Four Edges and Loaded with a Center Load W.

Author and Reference	Formula as Given by Author	Safe Load at Center of Plate $W=$	Unit Stress in Extreme Fiber of Material $f=$	Thickness of Plate in Inches $t=$
Grashof, Trautwines C. E. Pocket Book, Page 493	$f=\frac{3CWLl}{2t^2(L^2+l^2)}$ $C=2.$	$0.34\frac{ft^2(L^2+l^2)}{Ll}$	$3\frac{WLl}{t^2(L^2+l^2)}$	$1.73\sqrt{\frac{WLl}{f(L^2+l^2)}}$
Rankine, Civil Engineering, Page 543	$M=\frac{3WL^4l}{8(L^4+l^4)}$ Where L is less than $1.19\,l$	$0.45\frac{ft^2(L^4+l^4)}{L^3l}$	$2.25\frac{WL^3l}{t^2(L^4+l^4)}$	$1.5\sqrt{\frac{WL^3l}{f(L^4+l^4)}}$
Rankine, Civil Engineering, Page 543	$M=\frac{Wl}{4}$ being the same as for a plate supported at side edges only	$0.67\frac{fLt^2}{l}$	$1.5\frac{Wl}{Lt^2}$	$1.225\sqrt{\frac{Wl}{fL}}$

Rectangular Flat Plates, Firmly Secured along all Four Edges and Loaded with a Center Load W.

Grashof, Trautwines C. E. Pocket Book, Page 493	$f=\frac{3CWLl}{2t^2(L^2+l^2)}$ $C=1.75$	$0.38\frac{ft^2(L^2+l^2)}{Ll}$	$2.62\frac{WLl}{t^2(L^2+l^2)}$	$1.6\sqrt{\frac{WLl}{f(L^2+l^2)}}$

M = Maximum Bending Moment, Inch Pounds.
L = Long Span Between Supports.
l = Short Span Between Supports.
W, f, and t as given above

Note: Rankine gives Bending Moment M only as given in 2nd. line. Writer assumes Resisting Moment M_1 as $M_1=\frac{fLt^2}{6}$

Then $M=M_1$ or $\frac{3WL^4l}{8(L^4+l^4)}=\frac{fLt^2}{6}$ also $\frac{Wl}{4}=\frac{fLt^2}{6}$

Circular Flat Plates, Supported All Around The Edge, Loaded With a Total Load $W = PR^2\pi$, Uniformly Distributed Over The Unsupported Surface Area Of The Plate.

Author and Reference	Formula as Given by Author	Safe Load Per Unit of Surface Area $P =$	Radius of Plate to Supported Edge $R =$	Unit Stress in Extreme Fibers of Material $f =$	Thickness of Plate, Inches $t =$	Total Safe Load $= PR^2\pi = W =$	Deflection at Center of Plate $Y =$
Reuleaux, Trautwines C. E. Pocket Book 1906, Page 493	$P = \frac{ft^2}{R^2}$	$\frac{ft^2}{R^2}$	$t\sqrt{\frac{f}{P}}$	$\frac{PR^2}{t^2}$	$R\sqrt{\frac{P}{f}}$		$\frac{5PR^4}{6Et^3}$
	$t = R\sqrt{\frac{P}{f}}$			$0.314\frac{W}{t^2}$	$0.56\sqrt{\frac{W}{f}}$	$3.142ft^2$	$0.265\frac{WR^2}{Et^3}$
Grashof, Kent's, M. E. Pocket Book 1903 Page 900	$P = \frac{6ft^2}{5R^2}$	$1.2\frac{ft^2}{R^2}$	$1.095t\sqrt{\frac{f}{P}}$	$0.833\frac{PR^2}{t^2}$	$0.913R\sqrt{\frac{P}{f}}$		$0.7\frac{PR^4}{Et^3}$
				$0.265\frac{W}{t^2}$	$0.515\sqrt{\frac{W}{f}}$	$3.77ft^2$	$0.223\frac{WR^2}{Et^3}$
Bach, Hütte Des Ingenieurs Taschenbuch	$f = \frac{CPR^2}{t^2}$	$1.15\frac{ft^2}{R^2}$	$1.07t\sqrt{\frac{f}{P}}$	$0.87\frac{PR^2}{t^2}$	$0.93R\sqrt{\frac{P}{f}}$		$0.7\frac{PR^4}{Et^3}$
	$C = 0.87$			$0.277\frac{W}{t^2}$	$0.526\sqrt{\frac{W}{f}}$	$3.6ft^2$	$0.223\frac{WR^2}{Et^3}$
Johnson, The Material of Construction, 1897, Page 73	$t = R\sqrt{\frac{P}{f}}$	$\frac{ft^2}{R^2}$	$t\sqrt{\frac{f}{P}}$	$\frac{PR^2}{t^2}$	$R\sqrt{\frac{P}{f}}$		No case given
				$0.314\frac{W}{t^2}$	$0.56\sqrt{\frac{W}{f}}$	$3.142ft^2$	No case given

E = Coefficient of Elasticity. $\pi = 3.1416$

Circular Flat Plates Firmly Secured All Around The Edge, Loaded With a Total Load $W = PR^2\pi$, Uniformly Distributed Over The Unsupported Surface Of The Plate.

Author and Reference	Formula as Given by Author	Safe Load Per Unit of Surface Area $P=$	Radius of Plate to Supported Edge $R=$	Unit Stress in Extreme Fiber of Material $f=$	Thickness of Plate, Inches $t=$	Total Safe Load $= PR^2\pi =$ $W=$	Deflection at Center of Plate $Y=$
Reuleaux, Trautwines C.E. Pocket Book, 1906 Page 493	$P=\frac{3}{2}f\left(\frac{t}{R}\right)^2$	$1.5\frac{ft^2}{R^2}$	$1.225t\sqrt{\frac{f}{P}}$	$0.667\frac{PR^2}{t^2}$	$0.8165R\sqrt{\frac{P}{f}}$		$\frac{PR^4}{6Et^3}$
	$t=R\sqrt{\frac{2}{3}\frac{P}{f}}$			$0.2\frac{W}{t^2}$	$0.46\sqrt{\frac{W}{f}}$	$4.7ft^2$	$0.053\frac{WR^2}{Et^3}$
Grashof, Kent's M.E. Pocket Book, Page 283	$f=\frac{2PR^2}{3t^2}$	$1.5\frac{ft^2}{R^2}$	$1.225t\sqrt{\frac{f}{P}}$	$0.667\frac{PR^2}{t^2}$	$0.8165R\sqrt{\frac{P}{f}}$		$\frac{PR^4}{6Et^3}$
	$t=\sqrt{\frac{2R^2P}{3f}}$						
	$P=\frac{3ft^2}{2R^2}$			$0.2\frac{W}{t^2}$	$0.46\sqrt{\frac{W}{f}}$	$4.7ft^2$	$0.053\frac{WR^2}{Et^3}$
Johnson, The Materials of Construction, Page 73	$f=\frac{3PR^2}{4t^2}$	$1.34\frac{ft^2}{R^2}$	$1.154t\sqrt{\frac{f}{P}}$	$0.75\frac{PR^2}{t^2}$	$0.866R\sqrt{\frac{P}{f}}$		No Case Given
	$t=\frac{R}{2}\sqrt{\frac{3P}{f}}$			$0.239\frac{W}{t^2}$	$0.49\sqrt{\frac{W}{f}}$	$4.19ft^2$	No Case Given

E = Coefficient of Elasticity $\pi = 3.1416$

Flat Circular Plates Loaded With a Concentrated Load W Applied At a Circumference, The Radius Of Which Is r_0.

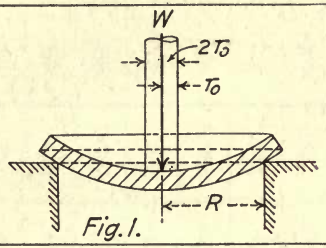


Fig. 1.

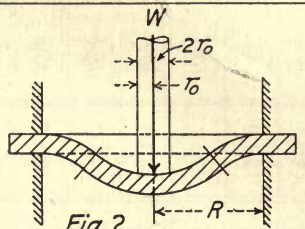


Fig. 2.

Plate Supported All Around The Edge, Fig. 1.

Author and Reference	Formula as Given by Author	Unit Stress in Extreme Fibers of Material, Lbs. per sq. Inch $f=$	Thickness of Plate in Inches $t=$	Safe Load $W=$	Deflection at Center of Plate, Inches $Y=$
Bach, Hutte, Des Ingenieurs Taschenbuch	$f=\frac{3C_1}{\pi}\left(1-\frac{2}{3}\frac{r_0}{R}\right)\frac{W}{t^2}$ $C_1=1.5$	$1.433\frac{W\left(1-\frac{2}{3}\frac{r_0}{R}\right)}{t^2}$	$1.2\sqrt{\frac{W\left(1-\frac{2}{3}\frac{r_0}{R}\right)}{f}}$	$0.7\frac{ft^2}{\left(1-\frac{2}{3}\frac{r_0}{R}\right)}$	$0.5\frac{WR^2}{Et^3}$
Grashof, Kent's M.E. Pocket Book, Page 284	$f=\left(\frac{4}{3}\text{Nat. Log.}\frac{R}{r_0}+1\right)\frac{W}{\pi t^2}=\frac{CW}{\pi t^2}$ $C=\left(\frac{4}{3}\text{Nat. Log.}\frac{R}{r_0}+1\right)$	$\frac{CW}{\pi t^2}$	$\sqrt{\frac{CW}{\pi f}}$	$\frac{\pi t^2 f}{C}$	$0.53\frac{WR^2}{Et^3}$

See Table Below.

Table Giving Values of C. (Grashof)

$\frac{R}{r_0}=$	10	20	30	40	50
$C=$	4.07	5.00	5.53	5.92	6.22

$C=\left(\frac{4}{3}\text{Nat. Log.}\frac{R}{r_0}+1\right)$

Plate Firmly Secured All Around The Edge, Fig. 2.

Grashof, Hutte, Des Ingenieurs Taschenbuch	$f=\frac{1}{\pi}\frac{4}{3}\text{Nat. Log.}\frac{R}{r_0}\frac{W}{t^2}$	f $0.424\frac{W}{t^2}\text{Nat. Log.}\frac{R}{r_0}$	t $0.65\sqrt{\frac{W\,\text{Nat. Log}\frac{R}{r_0}}{f}}$	W $2.36\frac{ft^2}{\text{Nat. Log}\frac{R}{r_0}}$	Y $0.48\frac{WR^2}{Et^3}$

E = Coefficient of Elasticity. $\pi = 3.1416$

CONVERTING STRENGTH OF WIRE TO STRENGTH PER SQUARE INCH—I

Diam.	Factor	Diam.	Factor	Diam.	Factor	Diam.	Factor	Diam.	Factor
.001	1256832	.026	1883	.051	489.9	.076	220 4	.101	124 8
.002	314208	.027	1747	.052	470.8	.077	214.8	.102	122.4
.003	141440	.028	1624	.053	452.7	.078	209.3	.103	120 0
.004	78552	.029	1514	.054	436.7	.079	204.1	.104	117 7
.005	50912	.030	1431	.055	421 3	.080	198.9	.105	115.5
.006	35360	.031	1325	056	406.0	.081	194 1	.106	113 3
.007	25984	.032	1243	.057	392.2	.082	189.4	.107	111 2
.008	19888	.033	1169	.058	378.4	.083	184.7	.108	109.2
.009	16288	.034	1106	.059	368.0	.084	180.0	.109	107.2
.010	12728	.035	1040	.060	357.7	.085	176 0	.110	105.2
.011	10520	.036	982	.061	344.4	.086	172.1	.111	103.2
.012	8840	.037	930	.062	331.2	.087	168.2	.112	101 5
.013	7532	.038	882	.063	321.0	.088	164.4	.113	99.7
.014	6496	.039	839	.064	310.8	.089	160.8	.114	98 0
.015	5724	.040	796	.065	301 5	.090	157.2	.115	96.3
.016	4972	.041	759	.066	292.3	.091	153.6	.116	94 6
.017	4404	.042	722	.067	283.8	.092	150.0	.117	93.0
.018	4072	.043	690	.068	275.3	.093	147.0	.118	91. 4
.019	3527	.044	658	.069	262.6	.094	144 1	.119	89.9
.020	3182	.045	629.6	.070	260.0	.095	141 1	.120	88 4
.021	2888	.046	601.7	.071	252.8	.096	138.2	.121	86.9
.022	2630	.047	577.1	.072	245.6	.097	135.4	.122	85.5
.023	2407	.048	552.5	.073	239.0	.098	132.6	.123	84.1
.024	2210	.049	530.7	.074	232.5	.099	129.9	.124	82.8
.025	2036	.050	509.0	.075	226.4	.100	127.3	.125	81.4

Contributed by J. F. Howe, MACHINERY'S Data Sheet No. 76. Explanatory note: Page 38.

CONVERTING STRENGTH OF WIRE TO STRENGTH PER SQUARE INCH—II

Diam.	Factor	Diam	Factor	Diam	Factor	Diam	Factor	Diam.	Factor
.126	80.0	.151	55.8	.176	41.0	.201	31.5	.226	24.9
.127	78.8	.152	55.0	177	40.6	.202	31.2	.227	24.7
.128	77.7	.153	54.3	.178	40.1	.203	30.9	.228	24.5
.129	76.5	.154	53.7	179	39.7	.204	30.6	.229	24.3
.130	75.3	155	53.0	.180	39.3	.205	30.3	.230	24.1
.131	74.1	.156	52.3	.181	38.9	.206	30.0	.231	23.85
.132	73.0	.157	51.6	182	38.4	.207	29.7	.232	23.6
.133	71.9	.158	51.0	.183	38.0	.208	29.4	.233	23.4
134	70.9	159	50.3	.184	37.6	.209	29.3	.234	23.2
.135	69.8	160	49.7	.185	37.1	.210	28.8	.235	23.0
.136	68.8	.161	49.1	186	36.7	.211	28.55	.236	22 8
137	67 8	162	48.5	187	36.3	.212	28.3	.237	22.65
138	66.9	163	47.9	188	36.0	.213	28.05	.238	22.5
139	65.9	.164	47.3	.189	35.7	.214	27.8	.239	22.3
140	65.0	165	46.7	190	35.3	.215	27.55	.240	22.1
141	64.0	.166	46.2	191	34.9	.216	27.3	.241	21.9
142	63.0	.167	45.6	.192	34.5	217	27.05	.242	21.7
143	62.2	.168	45.1	.193	34.1	.218	26.8	.243	21.55
144	61 4	169	44.5	.194	33.8	.219	26.55	.244	21.4
.145	60.5	.170	44.0	195	33.5	.220	26.3	.245	21.2
.146	59.7	.171	43.5	.196	33.1	.221	26.05	.246	21.0
.147	58.9	.172	43.0	.197	32.8	.222	25.8	.247	20.85
148	58.1	173	42.5	.198	32.5	.223	25.6	.248	20.7
149	57.3	174	42.0	.199	32.1	.224	25.4	.249	20.55
150	56.6	.175	41.5	.200	31.8	.225	25.15	.250	20.4

Contributed by J. F. Howe, MACHINERY'S Data Sheet No. 76. Explanatory note: Page 38.

ing the power applied to the toggle-joint.]MACHINERY's Reference Series No. 22, Calculations of Elements of Machine Design, Chapter VII, Toggle-Joints.]

Falling Bodies

Under the influence of gravity alone, all bodies fall to the earth with the same velocity. A body falling freely, from rest to the earth, acquires during the first second a velocity of about 32 feet per second, at the end of the second second a velocity of about $32 + 32 = 64$ feet, and at the end of the third second, $64 + 32 = 96$ feet per second, etc. The acceleration due to gravity varies slightly according to the location of the place where it is measured, and is 32.16 feet per second in the vicinity of New York. A definite relation thus exists between the distance a body would fall in a given time, and the velocity it attains during the fall. On pages 20, 21, and 22 are given formulas for the relation between the head in feet, the velocity in feet per second, and the time in seconds, and a table is calculated for heads varying from 0.01 foot to 1,000 feet, giving the velocities obtained by the falling body at the end of its fall, and the time required for traversing the given distance. [MACHINERY's Reference Series No. 5, First Principles of Theoretical Mechanics, Chapter VIII, Falling Bodies.]

STRENGTH OF MATERIALS

Tables and Formulas for the Strength of Materials

On page 23 is given a table of the strength of ordinary materials used in the mechanical trades. In the lower part of the table the elementary formulas for the strength of materials, together with a formula and values for calculating the strength of columns subjected to bending, are given. [MACHINERY, June, 1905, Notes on the Strength of Beams, Plates and Columns; MACHINERY, January, 1908, The Elastic Limit and the Testing of Materials; MACHINERY's Reference Series No. 22, Calculations of Elements of Machine Design, Chapter I, The Factor of Safety.]

Formulas for the Strength of Flat Plates

The machine designer is often called upon to carry out designs consisting in part of flat surfaces, such as plates supported or fixed at the edges, with or without intermediate supports or ribs. Exact formulas for finding the bending moments of flat plates, and their resistance to the stresses created by pressures normal to their surfaces, have not been determined. The formulas given by different authorities are founded on assumptions, and they should be considered as approximations only; they should be used with caution, as the results obtained are not likely to be very accurate. In devising such formulas, all the assumptions should be made to err on the safe side.

Square Plates

A square cast iron plate fixed or rigidly held at the edges and loaded with a uniformly distributed load, or a load concentrated at its center, would be likely to fail as shown in Fig. 1. It would first fracture along the diagonal lines from A to B, and then fail at or near the fixed edges along lines $B\,B$. The plate, of course, might also shear off along the edges $B\,B$, depending upon the method of loading the span L be-

(Continued on page 36.)

RATIO OF OUTSIDE RADIUS TO INSIDE RADIUS OF THICK CYLINDERS

Allowable Stress of Metal per square inch Section	Working Pressure in Cylinder, Pounds per Square Inch.												
	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500	7000
2000	1.732												
2500	1.527	2.000											
3000	1.414	1.732	2.236										
3500	1.341	1.581	1.915	2.449									
4000	1.291	1.483	1.732	2.081	2.645								
4500	1.253	1.414	1.612	1.871	2.236	2.828							
5000	1.224	1.362	1.527	1.732	2.000	2.380	3.000						
5500	1.201	1.322	1.464	1.633	1.844	2.121	2.516	3.162					
6000	1.183	1.291	1.414	1.558	1.732	1.949	2.236	2.645	3.316				
6500		1.264	1.374	1.500	1.647	1.825	2.049	2.345	2.768	3.464			
7000		1.243	1.341	1.453	1.581	1.732	1.914	2.144	2.449	2.886	3.605		
7500		1.224	1.314	1.414	1.527	1.658	1.813	2.000	2.236	2.549	3.000	3.741	
8000		1.209	1.291	1.381	1.483	1.599	1.732	1.889	2.081	2.323	2.645	3.109	3.872
8500		1.194	1.271	1.354	1.446	1.548	1.666	1.802	1.963	2.160	2.408	2.738	3.214
9000		1.183	1.253	1.330	1.414	1.507	1.612	1.732	1.871	2.035	2.236	2.440	2.828
9500			1.235	1.306	1.386	1.472	1.566	1.673	1.795	1.936	2.104	2.309	2.569
10000			1.224	1.291	1.362	1.441	1.527	1.623	1.732	1.856	2.000	2.171	2.380
10500			1.212	1.274	1.341	1.414	1.493	1.581	1.678	1.789	1.915	2.061	2.236
11000			1.201	1.260	1.322	1.390	1.464	1.544	1.633	1.732	1.844	1.972	2.121
11500			1.193	1.247	1.306	1.369	1.437	1.511	1.593	1.683	1.784	1.897	2.027
12000			1.183	1.235	1.291	1.359	1.414	1.483	1.558	1.640	1.732	1.834	1.949
12500				1.224	1.277	1.333	1.393	1.457	1.527	1.603	1.687	1.779	1.878
13000				1.215	1.264	1.318	1.374	1.434	1.500	1.570	1.647	1.732	1.825
13500				1.206	1.253	1.303	1.357	1.414	1.475	1.541	1.612	1.690	1.775
14000				1.197	1.243	1.291	1.341	1.395	1.453	1.514	1.581	1.653	1.732
14500				1.189	1.233	1.279	1.327	1.378	1.432	1.490	1.553	1.620	1.693
15000				1.183	1.224	1.268	1.314	1.362	1.414	1.469	1.527	1.590	1.658
15500				1.177	1.216	1.258	1.304	1.348	1.397	1.449	1.504	1.563	1.627
16000				1.170	1.209	1.249	1.291	1.335	1.381	1.431	1.483	1.538	1.599

Formula: $\frac{R}{r} = \sqrt{\frac{S+P}{S-P}}$

S = Maximum allowable fibre stress per square inch,
R = Outer radius of cylinder, in inches,
r = Inner radius of cylinder, in inches,
P = Working pressure of liquid within cylinder

tween supports, and the thickness of the plate. If the plate were merely supported along all the four edges, it would be likely to fail by breaking along the diagonal lines *A B* only.

On pages 24 and 25 are given two tables of formulas for square flat plates. In the table on page 24 the plates are supported at all four edges and the load is uniformly distributed over the unsupported surface of the plate. Formulas given by different authorities are re-

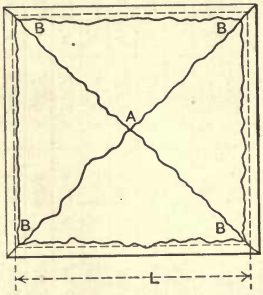


Fig. 1. Probable Manner of Rupture of Flat Square Plate, held at Edges

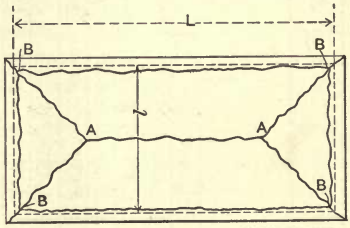
produced and the various values for total load, unit stress, etc., as obtained from the original formulas given by each authority, are given.

In the table on page 25 are given formulas for square flat plates secured along all four edges with the load uniformly distributed over the unsupported surface. Formulas are also given for square flat plates loaded at the center.

Rectangular Plates

In Fig. 2 is illustrated the probable manner of failure of a flat rectangular plate of cast iron loaded with a uniformly distributed load. The plate, if uniformly loaded and secured along all the four edges would probably fail by fracturing along the center line *A A* of the longer axis of the plate, and along the diagonal lines *A B*, and then fail at or near the edge of the support along the lines *B B*. If the plate were merely supported along all four edges, it would fail simply by fracturing along center line *A A* and the diagonal lines *A B*. As may be readily seen, the plate firmly secured at the edges offers a much greater resistance to the stress created by the load than does the plate merely supported at the edges.

In the table on page 26, a number of formulas for flat rectangular plates supported at all four edges and loaded with a uniformly distributed load are given. In the tables on page 27 are given formulas for flat rectangular plates firmly secured at all four edges and loaded with a uniformly distributed load. The fact that various authorities differ considerably, indicates the approximate nature of investigations along these lines. It is, however, important that formulas be deduced and used for designs of this character, because, while the formulas are only approximately correct, they indicate, in a general way, the dimensions required in flat plates, and the factor of safety assumed will always be taken large enough so that, practically, the difference between the various formulas is of small moment. It would be advisable, however, to use the



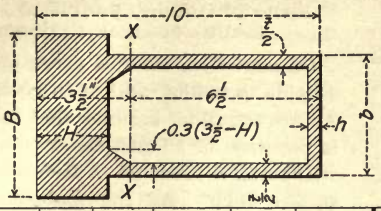
Machinery, N.Y.

Fig. 2. Probable Manner of Rupture of Flat Rectangular Plate, held at Edges

formulas which give the greatest dimensions, indicating that they are on the safe side. On page 28 will be found a table for rectangular flat plates supported or secured at all the four edges and loaded in the center; in the tables where only one set of formulas is given, it indicates that the authorities quoted in the other tables do not give formulas for the case in question. As the formulas here collected usually are found only by diligent search in a number of differ-

(Continued on page 38.)

PROPERTIES OF SECTIONS FOR PUNCH AND SHEAR FRAMES



S_c = Section Modulus for Compression,
S_t = Section Modulus for Tension,
A = Area of Section,
I = Moment of Inertia about Gravity Axis X-X

B	b	h=z/2	H	A	I	S_c	S_t	B	b	h=z/2	H	A	I	S_c	S_t
10	10	1/4	0.57	15.36	228.51	35.20	65.40	8	7	5/8	3.00	36.41	377.05	58.0	108.0
"	"	3/8	1.10	23.43	311.78	47.95	89.10	"	6	1/4	0.43	12.43	155.80	23.9	44.5
"	"	1/2	1.80	31.82	397.83	61.20	113.70	"	"	3/8	0.91	18.07	221.14	34.0	63.1
"	9	1/4	0.51	14.66	200.77	30.89	57.36	"	"	1/2	1.50	24.20	283.77	43.5	80.8
"	"	3/8	0.99	21.64	290.32	44.66	82.95	"	"	5/8	2.36	31.79	339.75	52.3	96.9
"	"	1/2	1.61	29.56	371.95	57.22	106.27	"	5	1/4	0.33	11.61	139.76	21.42	39.9
"	"	5/8	2.41	38.69	438.24	67.44	125.21	"	"	3/8	0.75	16.81	204.37	31.41	58.4
"	8	1/4	0.44	13.87	180.98	27.80	51.50	"	"	1/2	1.25	22.27	261.65	40.25	75.2
"	"	3/8	0.88	20.41	272.07	41.90	77.70	"	"	5/8	2.00	29.00	310.74	49.7	88.8
"	"	1/2	1.38	27.27	345.47	53.20	98.50	"	"	3/4	2.75	35.66	350.65	54.0	100.0
"	"	5/8	2.04	35.20	410.37	63.10	117.00	7	7	1/4	0.70	13.52	169.40	26.04	48.4
"	"	3/4	3.50	49.63	462.98	71.20	132.00	"	"	3/8	1.40	19.99	243.80	37.5	69.6
"	7	1/4	0.38	13.15	172.76	26.50	49.30	"	"	1/2	2.44	27.28	310.80	47.8	88.8
"	"	3/8	0.77	19.21	261.46	40.30	74.60	"	6	1/4	0.55	12.55	147.20	22.6	42.1
"	"	1/2	1.24	25.69	320.52	49.30	91.50	"	"	3/8	1.14	18.27	220.03	33.8	62.8
"	"	5/8	1.74	32.24	378.80	58.30	108.00	"	"	1/2	2.00	25.17	282.60	43.4	80.8
"	"	3/4	2.34	39.42	428.57	65.90	122.60	"	5	1/4	0.41	12.28	136.92	20.0	39.1
9	9	1/4	0.59	14.66	204.06	31.40	58.30	"	"	3/8	0.95	16.98	203.40	31.0	58.0
"	"	3/8	1.20	21.57	291.47	44.80	83.40	"	"	1/2	1.65	23.03	258.64	40.0	73.8
"	"	1/2	2.00	30.68	363.50	55.80	103.60	"	"	5/8	2.55	30.36	302.60	46.5	86.5
"	8	1/4	0.50	13.83	185.91	28.60	53.65	"	4	1/4	0.31	10.96	124.20	19.12	35.5
"	"	3/8	1.00	20.34	268.15	41.28	76.65	"	"	3/8	0.76	15.71	183.00	28.15	52.3
"	"	1/2	1.70	28.07	338.66	52.15	96.81	"	"	1/2	1.31	20.80	232.20	35.7	66.4
"	"	5/8	2.60	37.12	403.27	62.10	115.12	"	"	5/8	1.98	26.30	275.00	42.3	78.6
"	7	1/4	0.42	13.00	173.33	26.60	49.80	6	6	1/4	0.68	12.56	156.25	24.0	44.6
"	"	3/8	0.89	19.25	250.41	38.40	71.60	"	"	3/8	1.56	18.79	222.10	32.6	60.5
"	"	1/2	1.42	25.65	317.24	48.80	90.50	"	"	1/2	3.50	30.00	275.00	42.3	78.6
"	"	5/8	2.11	33.03	375.00	57.70	107.10	"	5	1/4	0.53	11.68	180.83	29.0	51.6
"	"	3/4	3.06	42.13	420.36	64.60	120.10	"	"	3/8	1.27	17.25	214.79	33.0	61.4
"	6	1/4	0.36	12.40	161.70	24.90	46.20	"	"	1/2	2.35	24.15	253.85	39.0	73.4
"	"	3/8	0.75	17.92	226.20	34.80	64.70	"	4	1/4	0.38	10.88	125.59	19.3	35.8
"	"	1/2	1.23	23.89	290.50	44.70	83.00	"	"	3/8	1.00	15.84	181.36	27.9	51.8
"	"	5/8	1.79	30.22	345.70	53.10	100.60	"	"	1/2	1.80	20.87	228.96	35.2	65.4
"	"	3/4	2.62	38.26	392.00	60.30	112.00	5	5	1/4	0.73	11.76	139.73	21.5	40.0
8	8	1/4	0.62	14.09	187.46	28.90	53.55	"	"	3/8	1.70	17.28	196.98	30.2	56.2
"	"	3/8	1.20	20.50	268.38	41.30	76.70	"	4	1/4	0.55	10.97	125.40	19.3	35.9
"	"	1/2	2.10	28.79	336.75	51.80	96.20	"	"	3/8	1.45	16.13	181.52	28.0	52.0
"	7	1/4	0.55	13.69	172.25	26.50	49.20	"	3	1/4	0.84	10.16	110.14	17.25	32.0
"	"	3/8	1.10	19.50	248.56	38.30	71.10	"	"	3/8	1.12	14.90	167.70	25.70	47.6
"	"	1/2	1.90	27.07	315.01	48.50	90.00	"	"	1/2	2.10	19.99	198.57	30.50	56.8

Contributed by Alton L. Smith, MACHINERY'S Data Sheet No. 132. Explanatory note: Page 38.

ent hand-books, and as these hand-books may not always be easily procurable, the collection will undoubtedly prove useful to designers who, at some time or other, may be called upon to lay out a design involving square or rectangular flat plates.

Formulas for Strength of Flat Circular Plates

When a flat circular plate becomes deformed under the action of a load applied normally to its surface, the upper fibers of the material are subjected to compressive stresses both radially and circumferentially, while the lower fibers are subjected to tensile stresses both radially and circumferentially. This is caused by the fact that the plate, when bending, tends to assume a spherical shape. The deformation of the plate tends to decrease the length or circumference of the upper fibers, while it tends to increase the length of the lower fibers.

On pages 29, 30 and 31, several sets of formulas for circular plates are given, selected from different authorities. The formulas are presented as given by the various writers, and then the different quantities "safe load," "unit stress," "thickness of plate," etc., as deduced from the given formulas, are shown.

Converting the Strength of Wire into Strength in Pounds per Square Inch

On pages 32 and 33 a table is given of factors for converting the strength of wire into strength in pounds per square inch. One column is given headed "Diam.," and one "Factor." The strength of the wire of a given diameter should be multiplied by the factor given, in order to obtain the strength per square inch. For example, if we know that a wire 0.035 inch in diameter can sustain a load of 150 pounds before breaking, then the strength per square inch of this wire is $150 \times 1040 = 156{,}000$ pounds per square inch. The factor 1040 is found opposite the diameter 0.035 on page 32. The table is very convenient for calculations of this kind, as it saves the finding of the area of the wire.

Ratio of Outside Radius to Inside Radius of Thick Cylinders

On page 35 a table is given of ratio of outside to inside radii of thick cylinders. As an example, assume that a cylinder is required of 10-inch inside diameter to withstand a pressure of 2500 pounds per square inch. As the material is cast iron, the allowable stress in this case would be 6000 pounds per square inch. To solve the problem, locate the allowable stress per square inch in the left-hand column of the table, and the working pressure at the top of the columns. Then we find that the ratio between the outside and inside radii in this case should be 1.558, and hence the outside diameter of the cylinder should be 10×1.558, or about 15 5/8 inches. The formula given in the upper right-hand corner of the table is the one on which the table is based. [MACHINERY, July, 1909, Thick Cylinders; MACHINERY'S Reference Series No. 17, Strength of Cylinders.]

Properties of Sections for Punch and Shear Frames

The convenience of the tables of properties of rolled steel sections as published in the structural steel makers' hand-books impresses anyone who has occasion to compute the strength of such material. Machine frames cannot be standardized sufficiently to permit of similar tables which would be useful to the designer of machinery, but it is with a view to the simplifying of the work of selecting proper sections for punch and shear frames that the table on page 37 has been compiled. The values were computed by slide rule, and it is believed that they are accurate enough for all practical purposes.

To illustrate the use of the table, consider the punch frame shown diagrammatically in Fig. 3. The "reach," or distance from the center line of punch to the back of gap, is 24 inches. Assume

that the maximum pressure, P, tending to force the jaws apart is that due to punching a 1-inch circular hole in soft steel plate 1 inch thick, or say about 157,000 pounds. Consider the section at TX. The action of P is such as to produce a tensile stress on the section to the left of the neutral axis N, with a compressive stress to the right of N, both due to flexure; and, besides, there

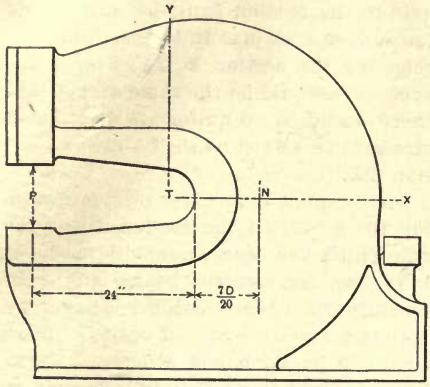


Fig. 3. Typical Punch Frame

is a tensile stress distributed uniformly over the section.

It is usually sufficient to determine the maximum tensile stress to the left of N.

Maximum tensile stress = flexure tensile stress + uniformly distributed tensile stress.

$$\text{Flexure tensile stress} = \frac{\text{Moment of } P \text{ about } N}{\text{Tensile section modulus of section } TX}$$

$$\text{Uniformly distributed tensile stress} = \frac{P}{\text{Area of section } TX}.$$

Assume 3000 pounds per square inch as the allowable maximum tensile stress for cast iron.

Assume that D in Fig. 4 is about 30 inches. Then $\frac{7D}{20} = 10\frac{1}{2}$ inches. If the stress due to flexure only is considered, the required section modulus for tension would be

$$\frac{157{,}000 \times (24 + 10\frac{1}{2})}{3000} = 1800, \text{ about.}$$

As no allowance has been made for the additional tensile stress uniformly distributed over the section, a section must be selected whose tension modulus is somewhat greater than 1800, say about 2500.

The table on page 37 gives a great variety of shapes and proportions, the only dimensions common to all being the depth of section, D, and the distance of the neutral axis from the extreme tension fiber. This location of the neutral axis represents average practice and insures an economical distribution of metal. Generous fillets and rounded corners should, of course, be used on the final section.

Suppose that a deep narrow section is desired, similar to that in Fig. 4, in which the dimensions are as follows: $D = 10$ inches, $B = 7$ inches, $b = 4$

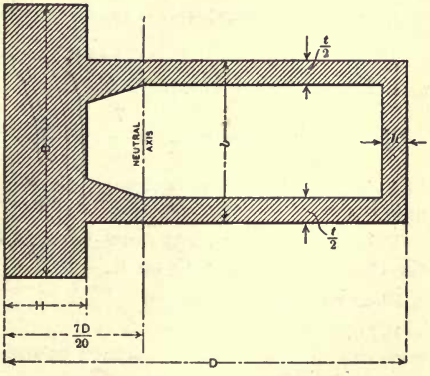


Fig. 4. Section of Punch Frame

inches, $H = 1.98$ inch, $\frac{t}{2} = h = \frac{5}{8}$ inch, A (area) = 26.3 square inches, and S_t (section modulus for tension) = 78.6. This section, taken from the table, is not, of course, large enough, but a similar one which is large enough may be found easily as follows:

If two sections A and B are similar in all respects, then

$$\frac{\text{Area of } A}{\text{Area of } B} = \frac{(\text{Any dimension of } A)^2}{(\text{Corresponding dimension of } B)^2}, \text{ and}$$

$$\frac{\text{Section modulus of } A}{\text{Section modulus of } B} = \frac{(\text{Any dimension of } A)^3}{(\text{Corresponding dimensions of } B)^3}.$$

$$\frac{\text{Required section modulus}}{\text{Modulus of section from the table}} = \frac{(\text{Required } D)^3}{(D \text{ of section from the table})^3}$$

Hence, $\frac{2500}{78.6} = \frac{(\text{Required } D)^3}{(10)^3}$. This last equation solved for D gives $D = 31.7$ inches, nearly. As the large section will be exactly similar to the small one, the area of the large section is found from the equation:

$$\frac{\text{Area of required section}}{26.3} = \frac{(31.7)^2}{(10)^2}$$

and area = 264 square inches, about.

The neutral axis will be $\frac{7}{20} \times 31.7$, or 11.1 inches from the extreme tension fiber.

This trial section may now be tested for the maximum stress on it.

$$\text{Flexure tensile stress} = \frac{157{,}000 \times (24 + 11.1)}{2500} = 2200 \text{ pounds}$$

per square inch, about.

$$\text{Uniformly distributed tensile stress} = \frac{157{,}000}{264} = 594 \text{ pounds per square inch,}$$

about.

The total tensile stress is, therefore, 2794 pounds per square inch.

If this result had not been near enough to the 3000 pounds per square inch assumed, another section could have been selected and worked out in the same way to get a closer result. The depth D of the required section being 31.7 inches as compared with 10 inches of the similar section given in the table, each of the dimensions of the required section will be 3.17 times the corresponding one given in the table. Hence $D = 31.7$, say 32 inches, $B = 22.2$, say 22 inches, $b = 12.7$, say 13 inches, $H = 6.3$, say 6½ inches, $t/2 = h = 1.98$, say 2 inches. The webs thicken gradually from the neutral axis to the tension flange so as to avoid too sudden a change in the section. For selecting the section at TY, Fig. 3, the procedure would be the same except that there would be no uniformly distributed stress to be added as in the case of section TX.

The method here given for determining the stress on the section TX is the one which has been commonly used. It is correct for straight beams and until recently has been considered approximately correct for curved beams. Investigations by Bach and others, however, indicate that the maximum stresses in curved beams of ductile material are very much greater than those found by the method used here; but a quick and accurate way of applying the new theory to general sections has not yet been devised. Cast iron punch frames whose sections have been determined by the old analysis have apparently stood up under their loads for years, although the maximum stresses in them as determined by the new analysis are so great as to threaten serious injury. Until the new theory has been more thoroughly verified by experiments, however, the old method will doubtless be used by most designers. [MACHINERY, November, 1903, Design of Punch and Riveter Frames; February, 1907, Strength of Punch and Shear Frames; August, 1908, The Designing of Machine Frames; December, 1909, The Design of Curved Machine Members under Eccentric Load; June, 1910, Limitations of the Common Theory of Flexure; MACHINERY'S Reference Series No. 24, Examples of Calculating Designs, Chapter II, The Designing of Machine Frames.]

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